Vol. IX. JULY, 1892. No. 3.

THE AMERICAN METEOROLOGICAL JOURNAL.

A MONTHLY REVIEW OF METEOROLOGY.

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BOSTON, NEW YORK, CHICAGO, AND LONDON.

GINN & COMPANY,

Publication Office, 7-13 Tremont Place, Boston, Mass., U.S.A.

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THE AMERICAN

METEOROLOGICAL JOURNAL.

VOL. IX. BOSTON, MASS., JULY, 1892. No. 3.

ON THE APPEARANCE AND PROGRESSIVE MOTION OF CYCLONES IN THE INDIAN REGION.

W. L. DALLAS, F. R. MET. SOC.

DURING the process of compiling the catalogue of the Arabian Sea cyclones, which forms Part IV. of the Indian Meteorological Department's Cyclone Memoirs, attention was attracted to various details connected with the appearance and progressive motions of cyclones, which, though out of place in what was primarily intended as a Sailor's Guide, were not without interest to the meteorologist. These details, together with some facts relating to other parts of the Indian region, are set forth in the following pages.

In the Indian region, at different seasons of the year, cyclones appear in three different situations. There are (1) the cyclones of the Arabian Sea, appearing principally in the spring and autumn; (2) the cyclones of northwestern India, appearing during the months from December to March; (3) the cyclones of the Bay of Bengal, appearing principally during the rains, viz., June to October.

We will first consider the common assumption as to the origin of cyclones, and, secondly, see if the cyclones of the Indian region agree with this assumption.

The common assumption is, that a cyclonic system arises from the unequal distribution of temperature over or above the earth's surface. Given a more or less circular area of abnormal heat, it is held that interchanging motions between the exterior and interior parts of the system will arise. It is also held that

this interchanging motion, owing to the deflecting force of the earth's rotation, will take the form of gyrations around the centre of abnormal temperature, and that from such a system a cyclone will arise. For this assumption the existence must be supposed of a previously formed hot calm area. Into and around this calm area the surface air circulates, and acquires an irregular ascending motion, at first scattered, but gradually concentrating, as the cyclonic influence extends and the great mass of the surrounding atmosphere is drawn towards the centre of agitation. To meet this conception, then, three requisites are presupposed: (1) the presence of a calm area, (2) the existence of abnormal heat within the calm area, and (3) a period of two or three days for the incubation of the storm.

In support of these three requisites the records of the Arabian Sea cyclones afford little reliable evidence. In a discussion on a storm in April, 1847, Piddington mentions that for some days previous to the appearance of the cyclone calms had prevailed near the Laccadives, in the neighborhood of which islands the storm subsequently appeared. This record is undoubtedly of importance, but it is not supported by later observations, as with this single exception the records which have been investigated gave no evidence whatever of any considerable period, such as two or three days, during which the characteristic of the weather antecedent to the appearance of a cyclone was calms and variable breezes. (2) With regard to the presence of an area of abnormal heat, there is equally little evidence in its support. On one occasion, viz,. between the dispersion of the Aden cyclone and the appearance of a second cyclone a day or two later off the west coast of India, an opportunity occurred for observing the temperature conditions existing previous to the appearance of a storm. The centre of the second cyclone, on June 6, 1885, lay in about latitude twelve degrees north and longitude seventy-one degrees east, and taking this point as the place of appearance of the cyclone, the following were the temperature readings recorded on the 5th nearest to the place of appearance: —

At 150	miles	N. W.	temperature	= 87	degrees	Fahrenheit.
" 200	"	W.	"	= 85	"	"
" 350	"	E.S.E.	"	= 88	"	"
" 300	"	E.	"	= 81	"	"

These temperatures are not all that could be desired as regards nearness to the place of appearance, but they give no evidence of any large excess of heat such as would be required by the hypothesis that the initial stages of a cyclone are due to temperature inequalities. In support of this, let a spot (Z on the chart) be selected in the Arabian Sea in, say, latitude ten degrees north and longitude seventy-three degrees east. The June temperature at this spot is 27°.83C., and the vapor tension 0.929″, which gives a dew-point depression of 3°.8C. Assuming that the vertical decrement of temperature is the same at the selected spot as that between the pair of stations in Southern India, Wellington, and Coimbatore, it amounts to 0°.55C. for each one hundred meters of ascent. Accepting these conclusions, and supposing that from any cause an upward impetus be given to the air over the selected spot, the following temperatures would be obtained at the different elevations, — A in the column of undisturbed air and B in the column of ascending air: —

Meters.	A.	B.
3,000	11.33	12.63
2,800	12.43	13.47
2,600	13.53	14.31
2,400	14.63	15.15
2,200	15.73	15.99
2,000	16.83	16.83
1,800	17.93	17.63
1,600	19.03	18.43
1,400	20.03	19.23
1,200	21.23	20.03
1,000	22.33	20.83
800	23.43	21.63
600	24.53	22.43
500	25.08	22.83
400	25.63	23.83
200	26.73	25.83
000	27.83	27.83

From these figures, it will be seen that, supposing the air over the sea surface have the same temperature over a considerable area, an ascending motion imparted to one portion would, during the first two thousand meters of ascent, occasion a diminution of temperature, so that to produce extensive cyclonic movements from a surface temperature inequality would prob-

ably imply a much higher surface temperature over a limited area than has yet been shown by observation to exist. (3) As regards a period of incubation the observations over the Arabian Sea favor a sudden rather than a gradual appearance of cyclonic storms. Dr. Buist, speaking of the Bombay cyclone of November, 1854, describes it as a great circular revolving disk which made its appearance *suddenly* on the afternoon of November 1, with already well-defined boundaries, and the writer, in the gales he has discussed, has obtained no conclusive evidence against the sudden appearance or in favor of a gradual appearance of cyclonic storms. Under these circumstances, it is difficult to avoid the conclusion that the cyclones of the Arabian Sea do not bear out the assumption as to formation as stated above.

The following table gives the monthly percentages of cyclonic frequency in the Arabian Sea: —

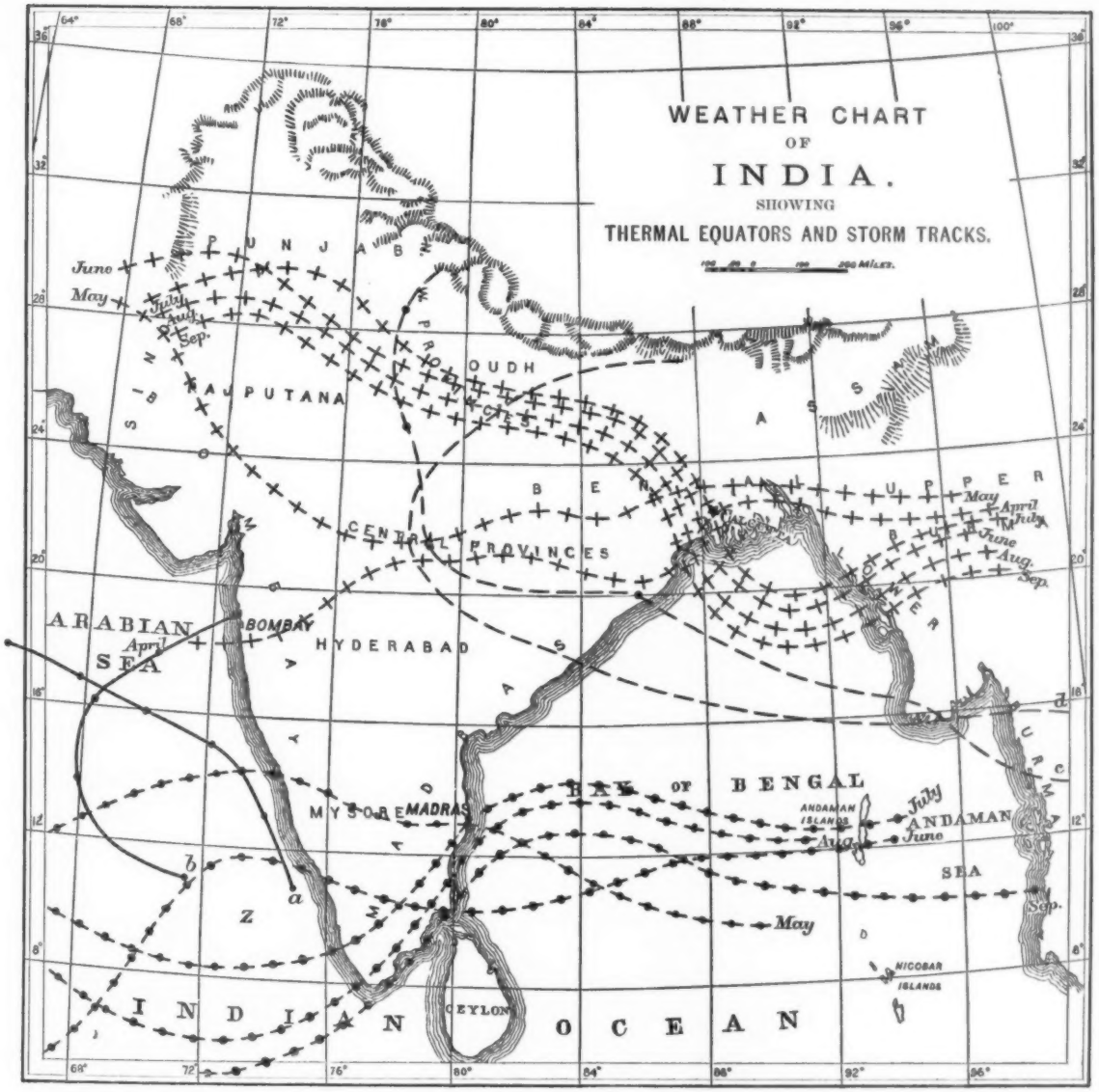
Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
5.7	0	3.8	13.2	18.9	20.7	1.9	0	1.9	11.3	20.7	1.9

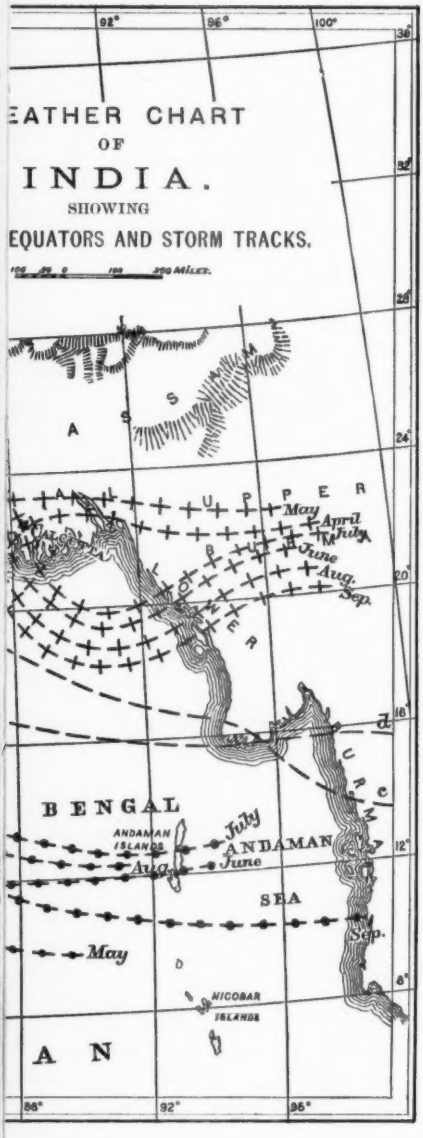
The epochs of greatest cyclone frequency are (*a*) the end of May and beginning of June, and (*b*) the beginning of November.

Now the direction of movement of the cyclones at these two epochs has a very important bearing on the subject under discussion. The following are the directions of advance on the successive days after distinct movement is traceable in the two cases: —

(*a*)	(*b*)
N. 4 W.	N. 59 W
N. 28 W.	N. 23 W.
N. 37 W.	N. 12 E.
N. 55 W.	N. 45 E.
N. 57 W.	N. 53 E.
N. 55 W.	

The cyclones of the pre-monsoon period (*a*) thus move first to north, then to north-northwest, then to northwest by north, and finally to west-northwest; while those of the post-monsoon period (*b*) move first to northwest by west, to then north-north-


WEATHER CHART
OF
INDIA.
SHOWING
THERMAL EQUATORS AND STORM TRACKS.
100 MILES.
PUNJAB
RAJPUTANA
OUDH
BENGAL
CENTRAL PROVINCES
UPPER
LOWER
ARABIAN SEA
BOMBAY
HYDERABAD
MADRAS
MYSORE
BAY OF BENGAL
ANDAMAN ISLANDS
ANDAMAN SEA
NICOBAR ISLANDS
CEYLON
INDIAN OCEAN
June
May
July
Aug.
Sep.
April
a
b
c
d


EATHER CHART
OF
INDIA.
SHOWING
EQUATORS AND STORM TRACKS.
100 50 0 100 200 MILES.
92°
96°
100°
36°
32°
28°
24°
20°
16°
12°
8°
A
S
S
U P P E R
May
April
July
June
Aug.
Sep.
BENGAL
ANDAMAN ISLANDS
July
ANDAMAN
June
Aug.
SEA
Sep.
May
NICOBAR ISLANDS
A N
86°
92°
96°

west, then to north by east, then to northeast, and finally to east-northeast. (See chart *a* and *b*.)

Having advanced the investigation of the storms which make their first appearance over the Arabian Sea so far, we will now turn to another class of disturbance, viz., the storms which enter the Arabian Sea from the eastward. These storms appear as distinct cyclones over the Bay of Bengal and strike the Indian peninsula on the Madras coast. As they cross the peninsula the cyclonic movements at the earth's surface are broken up by the rough land in the interior, and this disintegration is continued to higher and higher levels as the cyclone approaches the west coast, where the mountains form an almost uninterrupted barrier of between three thousand and seven thousand feet in height. As the storms cross these mountains the indications of a cyclone at the earth's surface become very faint; but, arguing from the subsequent appearance of cyclonic phenomena in the direct line of advance of the disappearing storm, it seems fair to conclude that the revolving whirls confined to a very elevated stratum of the atmosphere, whence friction has largely disappeared, have continued their horizontal translation uninterruptedly. When these disks have passed the mountain range and appeared over an oceanic track, where the moisture of the atmosphere is great, the lower surface of the whirl draws damp air into ascent, condensation takes place, the energy of the cyclone is increased, and the system, under favorable conditions, works down again to the sea surface.

For evidence on this subject reference must be made to the Cyclone Memoir, alluded to above, merely remarking here that, so far as can be judged, a cyclone, except when it is advancing towards an air current of greater hygrometric quality than the air in which it finds itself, loses in definiteness as soon as it passes from a sea to a land surface, and that its definiteness is at its minimum when the storm is crossing high mountains and the whirl is confined to the dry regions of the upper atmosphere.

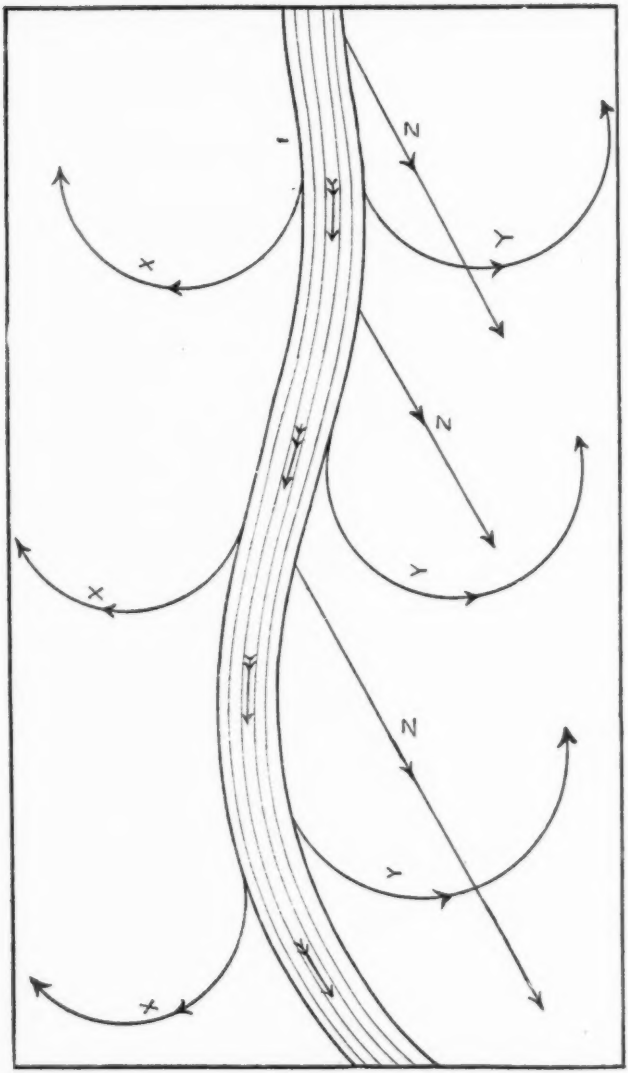
We will now turn to the second class of cyclones, viz., the winter cyclones of northwestern India. Mr. F. Chambers, late Meteorological Reporter for Western India, was the first to suggest that these storms travelled towards India from the westward, and there is now very little doubt that they are phenomena of the upper currents, and that they are borne along in the massive

current of easterly translation which prevails above the surface trade-wind circulation. All that we have at present to take into consideration is the general conditions which precede their appearance. These indications are ordinarily very slight while the storm is passing over a mountainous country. A considerable rise and fall of temperature, a slight fall and rise of the barometer, and an indefinite shift of wind at Quetta, Meshad, and the stations on the northwest frontier of India, are the ordinary indications of the approach of a depression, which, when it reaches the plains of India, becomes a well-defined disturbance. These changes and subsequent developments are there similar to the changes and developments which accompany the passage of a cyclone across the Indian Peninsula into the Arabian Sea, the comparative feebleness of the former over the latter being due to hygrometric differences, and to the fact that even on the plains of India the surface is less level than the surface of the sea.

Finally, there remain to be considered the cyclones of the Bay of Bengal during the southwest monsoon period. The monsoon season of 1891 was particularly fertile in cyclones, and one feature of the weather which was particularly noticeable was the barometric fall, the shift of wind, and the fall of rain over the Burmese Peninsula which preceded the appearance of a cyclone over the bay. Two or three instances of these changes may be quoted. On July 28 northwesterly winds were reported from Bhamo, Moulmein, and Tavoy, general rain was falling throughout Burma, and, though the barometer was rising briskly to rapidly over the greater part of northeastern India, the change at Bhamo and Tavoy was only +.001 in. On the following day the barometer was falling all over Burma, and over Central Burma there existed a shallow, ill-defined depression, which, on the 30th., entered the bay. This storm subsequently advanced into the head of the bay and into southwestern Bengal. Again, on Aug. 8, the barometer fell 0.06 in. at Bhamo with a westerly wind, and on the 4th. there was a northwesterly wind with heavy and continuous rain at Bhamo and Kendat, while the barometer was steady or falling in Upper Burma, though rising quickly in other parts of northwestern India. On the 5th. there was a brisk barometric fall over Bengal, and on the 6th. there was a well-marked depression over that province. On Aug.

23 a doubtful case occurred, the wind was again northwest at Bhamo, Rangoon, and Tavoy; but the only place in Burma where the barometer was falling was Tavoy. On the 24th. the barometric fall had extended to Moulmein, Rangoon, Tounghoo, Mandalay, and Kendat, while pressure continued to increase over the western half of Burma, and on the 25th. a largish depression appeared over the bay, while a recovery of pressure occurred over Burma. Again, on Aug. 27, the barometer fell briskly throughout Burma, and a small depression was shown over Central Burma, with an irregular cyclonic circulation of the winds. On the 28th. a general barometric rise occurred, but this did not affect the relative situation, and on the 29th. a well-marked depression was shown over the bay advancing northwestward. Many other instances of this sequence might be quoted, but without the aid of charts it is extremely difficult to describe meteorological changes satisfactorily, and it would be impossible in the space of the present article to give a series of charts to illustrate the progress of the changes indicated above. Finally, attention is directed to two storms which crossed the Tenasserim Peninsula, the first on Sept. 14 and 15, 1888, and the second on Sept. 19, 1891. The courses of these two storms are marked (*c*) and (*d*) on the accompanying chart.

Let us now consider the conclusions deducible from the various progressive motions of cyclones described above. In the late Prof. Ferrel's work on the winds, it is mentioned that over the equatorial region both theory and observation show that a current of westerly translation exists. Now it is obvious from the causes to which this current is assigned, that its position in latitude depends, not on the geographical but on the thermal equator. With certain modifications to be afterwards alluded to, the thermal equator travels north and south over the Indian region as the sun advances and retreats in declination, so that the current of westerly translation, which lies near the equator in the middle of March, advances as far north as latitude twenty-nine degrees by June and retreats to near the equator again by the middle of October. The course of the thermal equator in the different months is shown on the chart by lines of crosses. The following diagram shows the circulation which presumably exists in the superior layers of the atmosphere over the Indian region under normal conditions:—


N
Y
X
N
Y
X
N
Y
X

The shaded sinuous space in this diagram represents the current of westerly translation. The current lies over the thermal equator, and hence may exist anywhere between the geographical equator, and latitude twenty-nine degrees north ; its breadth is unknown, and its course must be sinuous as it agrees with the line of greatest heat, which, as shown by the lines of crosses on the chart, varies very considerably according to the physico-geographical peculiarities of the earth's surface. When this line of westerly translation is close to the equator, as in November, December, and January, there exist on the earth's surface the northeast and southeast trades flowing into the area of calms and variable breezes which prevails below the westerly current, and the air above flowing out according to the curved arrows shown on the diagram (*x* and *y*). Now the cyclones of the Indian region at this season follow a course which approximates closely to this movement of the upper currents ; some appear far in the south, flow along in the current of westerly translation for a greater or less distance, and are then cast out into the return current, which takes them towards the northern tropic along the curved course, which was given at (*b*) on page 102 and marked "x" in the diagram. Others appear in the north in latitudes twenty-four degrees to thirty-six degrees, and are borne along in the current of easterly translation which prevails in that part of the Indian region. In September and October the westerly current lies farther to the northward, the cyclones appear farther to the northward, and they either travel along westward in the current with that direction, or are thrown out and move off towards the north along the lines *x*. Such courses are shown by the September cyclones marked (*c*) and (*d*) on the chart. In June, July, and August the thermal equator and line of westerly translation lie across Burma, the north of the Bay of Bengal, and along the Gangetic plain, and thus coincide with the line of advance of the cyclones of the southwest monsoon period and with the trough of low pressure and variable breezes and calms which is characteristic of the pressure distribution of the monsoon season.

Provided, then, that it be conceded (1) that a current of westerly translation exists within the tropics (roughly) in the superior layers of the atmosphere, (2) that the air flows away northward and southward from this current along a curved course,

such as that shown in the diagram on page 106, it may perhaps be held that there exists a general agreement between the movements of most of the cyclones of the Indian region and these movements of the superior layers of the atmosphere.

Moreover, in addition to the above, we have evidence that, antecedent to the appearance of a cyclone in the Bay, when the cyclone appears to the north of latitude fifteen degrees, there occurs a barometric fall, a shift of wind, rain, and other indications of cyclonic action over the hilly country of the Burmese Peninsula; that antecedent to the appearance of a cyclone in Northern India there are similar manifestations over the mountainous region of Afghanistan and the Hindoo Koosh, and, finally, that when a cyclone passes across the Indian Peninsula from the Bay to the Arabian Sea the indications are extremely slight when the storm is crossing the hilly country in the centre of the peninsula, but that they reappear sometimes in all their former strength when the storm again reaches a sea surface. That a cyclone does work down from a superior elevation to the earth's surface when the storm reaches a favorable position and a favorable medium rests of course on circumstantial evidence, but the retreat of the cyclone into the upper atmosphere when the storm passes from a sea on to a land surface, has, so far as can be judged, been actually observed. On page 120 of the second part of the Cyclone Memoirs published by the Meteorological Department of the Government of India occurs the following passage: . . . "cloud observations, however, were made during the 22d. and 23d. at Calcutta which proved that though the lower currents were very feeble . . . and light airs and calms prevailed close to the ground, the clouds (which were comparatively low) were moving with extreme velocity. The change also in the direction of the cloud movements . . . distinctly showed that . . . the storm was advancing in a northerly direction" (from the Bay) "towards Calcutta. The movement of the clouds was of a rapidity that has been rarely equalled in the experience of the writer, extending over many years."

There is then evidence, either circumstantial or observed, that (1) cyclonic storms descend from and retreat to the superior layers of the atmosphere during their passage over the earth's surface; (2) that the cyclonic whirl may travel along in the upper atmosphere, giving only faint indications of its presence at the

earth's surface; (3) that the movements of cyclones agree generally with what may be supposed to be the movements of a superior layer of the atmosphere.

The whole of this evidence seems then to favor the assumption that cyclones are a production of the upper atmosphere; that they are eddies formed in the current of westerly translation; that they are borne along in this current till they reach the outer edge of the current, and that they are then thrown out, and in the northern hemisphere are carried first to west-northwest, then to northwest, then to north, and finally to northeast and east in the massive upper current which blows from the torrid towards the temperate zones.

In opposition to this conception of the production and of the cause of the progressive motion of cyclones, there is the evidence afforded by the cyclones of May and the first week of June in the Arabian Sea and the Bay of Bengal. The direction of motion of the Arabian Sea cyclones is given on page 102, and is directly opposed to the conception given above.

If it be supposed that the thermal equator at the end of May and beginning of June be in latitude twenty-three degrees to twenty-eight degrees north, the current of westerly translation in that latitude, and that cyclones appear within that current, the motion of cyclones over the Arabian Sea should be that shown by the arrows marked "*z*" in the diagram on page 106, and to account for this difference the following suggestion is put forward: It would appear from the temperature observations, that at all seasons of the year in the equatorial regions the mean temperature is either higher than in neighboring regions, or there exists a strong tendency towards the production of relatively high temperatures. When, however, the sun is at or near the summer solstice, and, as in the case of the Indian region, becomes vertical over a land surface, a line of abnormal heat is produced outside the tropics which is so intense as to mark the high temperature line in equatorial regions. The trade-wind circulation (if it may be so described) is then removed to this northern position, and with it the current of westerly translation. The equatorial westerly current, then, for practical purposes, is non-existent, but let the sub-tropical line of intense heat be modified by a fall of temperature, even to a moderate extent, then the tendency to the formation of the doldrum region

within the tropics immediately reasserts itself and a cyclone may appear within those limits. If the temperature disturbance in the north last for any time, the line of westerly translation within the tropics may exist for some days, and, as in the case of the Aden cyclone, carry storms formed within it away to the westward ; but when the temperature disturbance is only transitory the current of westerly translation disappears, and any storm formed is carried northward in the southeasterly current, feeding into the extra-tropical current of westerly translation.

The investigation into the progressive motion and appearance of cyclonic storms seems then to strengthen the argument that these phenomena originate in the upper atmosphere mainly within the current of westerly translation which exists over the tropics. Ferrel accounts for this current by a combination of forces resulting from (1) the trade-wind circulation, and from (2) the air movement from the Northern to the Southern Hemisphere in the summer of the Northern Hemisphere ; and from the Southern to the Northern Hemisphere in the summer of the Southern Hemisphere. Similarly, then, if from any cause a line of intense heat be produced over any other region than the equator, a resulting circulation will arise which will be similar *in some respects* to the trade-wind circulation of the tropics. Thus the Hon. Ralph Abercromby noticed that over the Gulf of Guinea, although the doldrum region lay to the north of the equator, so that under ordinary circumstances the deflecting force due to the earth's rotation should have produced westerly winds, yet "while the southeast trade, between the equator and the doldrums, turned into southwest on the surface, the upper winds come from southeast." From this, it may perhaps be permissible to argue, that at a moderate elevation over the Indian region southeast winds prevail blowing towards the axis of greatest heat in Northern India.

As regards the Bay, particular attention is drawn to the storms of Sept. 15, 1888, and of Sept. 19, 1891 (*c* and *d* on chart). These two storms entered the Bay from the Gulf of Siam, crossing the Tenasserim Peninsula far in the south, where the hills are only of slight elevation and where there is only one range. They would consequently appear over the Bay of Bengal more quickly and with better definition than would storms which have to cross Burma and which have several

ranges of hills to surmount before entering the Bay. We have, then, evidence that cyclones do advance into the Bay from the eastward, and we have evidence that prior to the appearance of a cyclone over the north of the Bay there occurs a fall of the barometer and other cyclonic indications over Burma, consequently is it advancing the argument too far to say that practically nearly all the monsoon storms of the Bay are carried to that region from the eastward, that their primary condition of indefiniteness is due to their having crossed an extensive land surface with transverse hills of considerable elevation, and that their secondary condition of definiteness is due to the working down of the cyclonic whirl under favorable atmospheric conditions? These favorable atmospheric conditions are: general uniformity of pressure so that the winds are light and variable, sultry weather, producing large accumulations of aqueous vapor in a comparatively still atmosphere. When into such conditions the cyclonic germ — if the whirl existing in the upper atmosphere may be so described — forces its way, the lower portion of the whirl draws moist air into ascent, and concentrated rainfall occurs over a limited area. A strong indraught is set up, and the system increases till an intense cyclonic storm is the result. In no case has a cyclonic storm been noticed developing in the full blast of the southwest monsoon, and it may probably be accepted as a general rule that a cyclonic whirl cannot work down from the upper atmospheric strata and form into a surface cyclonic storm without the presence of the antecedent favorable conditions noticed above.

There are no more important subjects awaiting solution by the meteorologists of the present time than those which deal (1) with the stratum of the atmosphere in which cyclones appear, and (2) with the controlling influence on the progressive motion of cyclones. If cyclones are as intimately connected with the upper currents as the above investigation would appear to show, this connection is an argument in favor of their generation in those currents, and the place of origin of cyclones would consequently be removed to a situation where actual observation becomes impossible. Nevertheless, when once the question is definitely settled, even should that settlement relegate the place of origin of cyclones to the upper atmospheric currents, meteorologists would probably experience but little

difficulty in so adjusting their observations as to enable them in time to estimate correctly the probability, in different years and in different regions, of that congestion of the upper currents happening on which the occurrence of cyclones would in that case depend. Still the change in the system of observation would necessarily be large, and in this lies the importance of an early and definite settlement of the question.

With regard to the controlling influence on the progressive motion of cyclones, all available evidence seems to show that this is centred in the movements of the upper atmosphere. That the surface distribution of land and water, of mountain and plain, of barometric pressure, of humidity, and of temperature, exerts an influence, is unquestionably true, but the average curves which the cyclones of the Indian region, of the Gulf of Mexico, and of the Pacific Ocean, describe, are so obviously similar to the curves which the upper currents of the atmosphere describe in their passage from the equator to the temperate zones that they form strong presumptive evidence that the relation between the two is that of cause and effect.

S. A. HILL, M. A., F. R. M. S., F. C. S.

A MEMOIR.

EDNA TAYLOR HILL.

On Sept. 23, 1890, the scientific world met with a great loss in the premature death of S. A. Hill, the professor of physical science at the Muir Central College, Allahabad, India. He was also meteorological reporter to the government of the Northwestern Provinces and Oudh, and a man of marked and solid ability, who had done yeoman's work in the cause of science in India.

Samuel Alexander Hill was born on Oct. 10, 1851, at Ballyboley, near Belfast, in the county of Antrim, Ireland. His ancestors were among the earliest English settlers in this part of Ireland, having come over with Sir Arthur Chichester in the reign of Queen Elizabeth.

Mr. Hill received his early education at the Ballyeaston School, which was under the Irish National Board, and began

to teach as a pupil teacher in the year 1867, when only sixteen years of age. In 1868 he went to the Government Training College in Dublin, where he was looked upon as of great ability and rare mental calibre. After staying there a little over a year, he was placed in the first class of teachers, and received an appointment as master of a new school in Lisburn, a considerable manufacturing town about twenty miles from his home, where he remained from May, 1869, to September, 1871. While

there, Mr. Hill entered as a competitor for a Royal Exhibition at the School of Mines, London, in which he was successful. This Exhibition was an allowance of fifty pounds a year for three years, with free admission to all the lectures, laboratories, etc., of the School of Mines. Here he studied under Prof. Huxley, winning distinguished favor. While going through this course Mr. Hill went up for the examinations of the London University. One of his fellow-students says: "He used to astonish us by the amount of work he got through, for he took his Associateship in all three divisions, and did the greater part of his work for the degree of bachelor of science at the same time, whilst most of us thought we did very well if we managed to get the associateship in two divisions at one time."

At the end of 1874 Mr. Hill took his degree, with honors in several subjects, and the distinction of "university scholar" in geology and palæontology. While he was still in London, Gen. Strachey, R. E., F. R. S., a member of the Indian Council, came from the India office to inquire if the authorities of the School of Mines could recommend a young man as a professor of physical science for the new college at Allahabad. This situation was at once offered to Mr. Hill. He accepted it, and on Feb. 24, 1875, the Marquis of Salisbury was pleased to appoint him to the position for five years. Mr. Hill left England very shortly to take up the professorship, in which chair he remained until the day of his death.

In May, 1875, the lieutenant-governor of the Northwestern Provinces appointed him to be the meteorological reporter to the Government, in addition to his lectures. This proved very congenial work. Mr. Hill immediately began to make use of the data now at his command, and commenced a series of most valuable papers on the subject of Meteorology, receiving the thanks of the Government of India in 1881 for his successful efforts to improve the study and utilize the teachings of Indian meteorology. He wrote frequently on the questions of the day for the daily newspapers. His last editorial sent to the *Pioneer* was a full and interesting account of the nature of the monsoon and the causes which modify the distribution of the rains. He describes the method by which meteorological reporters make their forecasts, as weather conditions are simpler, more massive, and consequently more persistent over India and the Indian Seas than perhaps in any other portion of the world, so that it is possible to forecast somewhat the character of the season. He explains the influence of the snow-fall of the previous winter and spring over the Himalayas on the monsoon, heat being the prime mover of the gigantic system of wind circulation over the Asiatic Continent and adjacent seas. He shows also that while the earth at any point is covered with snow its temperature can never rise above the freezing point, no matter how powerful the sun's rays may be; so that heavy and late snowfall on the Himalaya, the Pamir, and other mountain masses of Central Asia, must have a very powerful retarding and weakening effect upon the ensuing monsoon.

Mr. Hill was granted his first furlough after his laborious

work in a trying climate for eight years, in May, 1883. As his vacations from the College during the hot months of May and June had been spent travelling through the Northwestern Provinces and Oudh, and sometimes going in the interior of the Himalaya Mountains for the purpose of inspecting the various meteorological stations, this was a much-needed rest and change. The earlier portion of his furlough, which was for a year, afterward extended to eighteen months, he spent in Ireland and touring through Wales, but in September he started for a trip to America, choosing the steamship "Florida" which met such a sad fate the following year. On this voyage he met Miss Taylor, daughter of Rev. R. T. Taylor, D. D., president of Beaver College, Beaver, Penn., to whom Mr. Hill was married on June 26, 1884. This chance meeting in mid-ocean, particularly as a similar case had recently occurred, led a friend to say that "there seems to be something in ocean steamers especially fatal to the bachelor freedom of Indian meteorologists, and it leads one to speculate whether Davy Jones in company with Boreas and the gentle Auster does not conspire to take this haughty independence out of these impertinent fellows, who seek to pry into their secrets, when once they have them at their mercy."

Mr. Hill visited Niagara, the Thousand Islands, the White Mountains, and made a tour of the principal cities in the East, and later spend some time in the Southern States, where the social problems of the day much interested him. He was well posted in American geography and politics, and astonished his acquaintances by his intimate knowledge of affairs. It was often said of him that any statement that he made could be trusted. Mr. Hill described his wanderings in a most interesting style for the Indian papers.

While in London, in 1884, he attended the South Kensington Science Schools for some lectures, returning to India with his bride in October of that year.

His meteorological work was now given a fresh impetus through the completion of the new observatory building, the office having hitherto been in one half of Mr. Hill's house in Allahabad. A fully-equipped first-class observatory was now established at this station, with nineteen observatories reporting to the office. The electro-magnetic engraving meteorograph,

built by Van Rysselberghe for this observatory, was set up, interesting him much, but requiring constant care and thought, and untold patience with native workmen inexperienced in anything of that kind.

The Muir College, up to the year 1885, had been temporarily established in Lowther Castle. In this year the fine building which stands in the middle of a large plot of ground, and of which Lord Northbrook, the viceroy, had laid the foundation stone in December, 1873, was completed. This is considered the finest structure in the Northwest Provinces, excepting only the Taj. The architecture is of a modified Saracenic style, and the tower which the Mahárája of Vizianagram gave, and which is two hundred feet high, was speedily utilized by Mr. Hill for meteorological observation.

His students were very fond of him, and he could get thoughtful attentive work from these Hindus and Mahommedans, — too many of whom only work to pass their examinations in order that they may get into government service, — when no one else could arouse interest for the love of knowledge itself. He has been greatly missed by these students, for his ear was always open to their many requests, and often foolish applications, to which he listened with the greatest patience. He interested himself too in their debating societies, frequently going to their meetings in a close room, after a long, hard day's work. More than one hundred and fifty of these native students, in their academical robes, followed Mr. Hill to his last resting-place, to pay what little honor they were able to their distinguished professor, showing that these stolid Aryan brothers of ours had appreciation for the faithful work done for them.

When the question came up of establishing a university, Mr. Hill took an active part in the discussion, and in 1887, when the Act to establish a University of Allahabad was passed, he was appointed among the first Fellows and was chosen a member of the syndicate, the Executive Committee of the Senate. Sir Auckland Colvin, the lieutenant-governor, and the chancellor of the university, at the convocation following Mr. Hill's death, says: "We have lost in Mr. Hill, late the professor of physical science at the Muir College, and one of our most eminent Fellows, a pillar of strengh to the University. But though we have lost him, and though, with that appalling completeness which is

peculiar to the conditions of our life in India, every personal trace of him has disappeared from amongst us, we shall not let die his memory. He is not lost to us in truth, inasmuch as in the rules and regulations of the University are preserved the results of much of his labors. The balanced mind, the pursuit of knowledge for the love of knowledge, the philosophic temper, the calm indifference to the world's prizes, the science lightly worn, the patient suffering of foolishness, were the attributes which made Mr. Hill what we knew him; and these are the attributes which every graduate who passes through our college should humbly seek to attain. That acquired illumination, that habit, that personal possession, were the characteristics which eminently marked him as the educated man, and his the philosophic mind which we have been describing. It is a matter of peculiar grief to me that on this, the first occasion on which I have to address the members of this University, it should be necessary for me to deplore the loss of one amongst the most distinguished and most valued of our number. I will not say that he cannot be replaced in our councils, but I will assert that he who can replace him will have earned the right to be regarded as among the most trustworthy and most wise of those whose business it is to seek for and to secure a right solution of the problems which attend university instruction in these Provinces."

Mr. Hill's life in India was spent in the routine of college work, with inspection tours in the cause of meteorology at Christmas time, and in the hot-weather vacations, all the while contributing papers on the subject so near to his heart to the various scientific and meteorological societies. In 1888, in addition to his other work, at the request of Government he undertook to write a series of geographies for Indian schools. which were published under the authority of the Director of Public Instruction. The first book was a Geography of India, the second, a Geography of the World, and the third a Physical Geography, which he was peculiarly fitted to write. In a compact form, and in a style as easy as it is polished, he tells the story of nature as gleaned by centuries of patient inquiry, the results of which are only now becoming classified and the dawn seen by Milton brightening into daylight. This arrangement of the results of scientific research is no easy task to accomplish.

In the nineteenth century a man must come to his work armed with materials of solid substance, — there is nothing, says Oliver Wendell Homes, so effective with an opponent, — and the Professor of Physical Science at Allahabad University was in this respect well equipped. Whilst treating of the earth's features in a general sense, he never fails to bring the subject before the comprehension of the student, by illustrating a statement by reference to some well-known place, object, or aspect of India, wherein are contained so many of the most astonishing and magnificent of the enduring objects turned out from nature's workshop. These books were written in English, in Urdu, and in Hindi.

In September, 1888, Mr. Hill was given the supervision of the physical science class at the Queen's College, in Benares, where he went periodically. In 1889 the duties of water analyst for the Allahabad municipality were added to his other duties. In June, 1881, he had been elected a member of the Allahabad Public Library Committee, and later was made secretary. He took much interest in the work all through his service, and spent much valuable thought and many laborious hours over this library.

In March, 1889, Mr. Hill took nine months' furlough out of India. His travelling companion was the well-known author, Mr. Rudyard Kipling. who had been a warm personal friend for many months before their leaving India. These two went to Burma, the Straits Settlements, China, Japan, and across to America. Mr. Kipling, in his charming Letters, in which he describes their eccentric flight "From Sea to Sea," uses Mr. Hill as a mouthpiece for many of his theories, and one who knew the "Professor" can understand the respectful tenderness of Mr. Kipling's allusions to his companion. The Professor was "cursed with a large and active camera," and furnished a valuable collection of illustrations to the Letters.

After Mr. Hill's return to India, in December, 1889, accumulated work, especially in the Meteorological Department, met him, and as he had been appointed an Examiner of the Calcutta University, a large number of papers came in to be marked. In the midst of the examination of these he was attacked very severely by the influenza during its first appearance. He endeavored to complete his task, but was much

worn by the work. In April, when the college vacation came, he obtained a much-needed change to Simla, in the Himalaya Mountains, where he was summoned on special duty with the head Meteorological Office of India. The health-giving air of Simla seemed quite to restore him, and he returned to the plains the middle of July, apparently as strong and vigorous as any man in India, good for many a year's work. September proved a very trying month, owing to a continued break in the rains. Less than a week before his death, in writing a note to the *Pioneer* on the meteorological conditions of the country, he says of the weather: "We have had a fortnight's drought, accompanied by heat the like of which has not been felt in September since the year 1877." The thermometer stood at eighty-eight degrees in the house and at one hundred degrees out of doors. During this week Mr. Hill had a slight attack of Indian fever for a day, but was quite recovered and seemingly as well as ever when he was seized very suddenly with a violent headache; he became unconscious, congestion of the brain set in, and in less than twenty-four hours from the first warning he passed away quietly on the morning of September 23, 1890. It seems remarkable that his last thoughts and words should have been on Sir Auckland Colvin's "Minutes on Technical Education in India," which was published the evening before he died. In the discussion of this with a friend his mind seemed as active as ever. Sir Auckland, in an address to a school a day or two later, says: "I should like to be allowed to take this, the earliest opportunity which has been afforded me, to express what I know you all share, the deep grief with which I have learnt of the death of one of the most eminent professors who ever joined the ranks of the educational service in India. While his singular modesty, his great acquirements, and his manly and honest character were familiar to us all, the especial loss of a man of his type to Government, more especially in view of his value as a professor of those sciences which are closely allied with the subjects which I have more particularly just now at heart, and as a man from whose opinion on this matter I had hoped for the greatest assistance, is irreparable."

In recording the sad event the Allahabad *Pioneer* said: "In Mr. Hill the Government loses a servant whom it will be

very difficult to replace, — a man of most unusual powers of mind, who at a comparatively early age had made a European reputation for himself in his own particular study of meteorology. With none of the eccentricities of a disciple of science, but with all the modesty and virtue of the character, he will pass away from us respected by all and much more than respected by those who were privileged to know him with intimacy." Mr. Blanford, in a review of Indian Meteorology, in *Nature*, writes: "The frequent reference in the foregoing paragraphs to the admirable work of the late Prof. Hill forcibly brings before me how great a loss has been sustained by Indian science in his premature death, — a loss the more conspicuous in a country where the workers are few and the field of research so large and fruitful. It is but a sad consolation to offer this slight tribute to the memory of a man who was as modest and amiable as he was able and accomplished as a devotee of science; but all who know his work will cordially re-echo the words of the Governor-General in Council, — that the Meteorological Department of India lost in him an officer whose industry, talent, and technical knowledge it would be hard to replace."

Among Mr. Hill's contributions to science the following are published in the Indian Meteorological Memoirs: —

May 10, 1878. The Rainfall of Benares Considered in Relation to the Prevailing Winds.
Nov. 6, 1879. Variations of Rainfall in Northern India.
April 24, 1881. Some Results of the Meteorological Observations Taken at Allahabad During the Ten Years 1870–79.
. . . The Temperature of Northwestern India.
. . . Observations and Humidity at a Height of Forty Feet Above the Ground at Alapore Observatory, Calcutta.
. . . The Ground Observations made at the old Observatory, Allahabad.
. . . Temperature and Humidity Observations made at Allahabad at Various Heights Above the Ground.

The following papers were read before the Asiatic Society of Bengal: —

April 4, 1883. On the Measurement of Solar Radiation by Means of the Black Bulb Thermometer in Vacuo.
May 6, 1885. Observations of the Solar Thermometer at Lucknow.
Nov. 3, 1886. On Solar Thermometer Observations at Allahabad.
Aug. 23, 1888. The Psychrometer and the Condensing Hygrometer.

Nov. 7, 1888. The Tornadoes and Hail-Storms of April and May, 1888, in the Doab and Rohilkhand.

The following were read before the Royal Society of London : —

1881. On the Constituent of the Atmosphere that Absorbs Radiant Heat. Part I.

1882. The same. Part II.

1887. Some Anomalies in the Winds of Northern India, and their Relation to the Distribution of Barometric Pressure.

Other papers are : —

The Meteorology of the Northwest Himalaya. The Northwestern Provinces Gazetteer, October, 1881.

Influence of the Weather upon Death-rate and Crime in India, *Nature*, XXIX, 1884, 338.

Prof. Langley's Researches on Solar Heat. A Criticism of Certain Points. Quart. Jour. Royal Met. Soc., XIII, 1887, 85.

The Life Statistics of an Indian Province, *Nature*, XXXVIII, 1888, 245, 565.

Ueber die jährliche Schwankung des Barometers in Indien. Meteorolog. Zeitschrift, V., 1888, 340.

BEAVER, PA., May, 1892.

PAPERS FROM THE PHYSICAL GEOGRAPHY LABORATORY OF HARVARD COLLEGE.

No. 6. — THE EYE OF THE STORM.

(Continued.)

SIDNEY M. BALLOU.

DISCUSSION OF THE METEOROLOGICAL PHENOMENA.

Espy's Theory. — As long ago as 1857, Espy* presented an elaborate explanation of the phenomena connected with the eye of the storm. This explanation, however, was based upon the theory that the storm was a radial indraft of air towards a centre, with no whirl ; and, therefore, is not in accord with the modern knowledge of cyclones. As one of the earliest, if not the first discussion of the subject, it may be worth quoting.

* Fourth Met. Report, Wash. 1857, 130.

"Now, it is quite probable that in so long a band (the belt of low pressure when south of the equator), the inward motion below and the upward motion in the middle will be more violent in some places than in others, and, of course, a more rapid condensation of vapor and evolution of latent caloric, and a greater fall of the barometer; if so, there would be an inward motion on all sides towards one common centre; and, as the wind on the north of this centre would be blowing from the northwest, and the wind on the south of the centre would be blowing from the southeast, it is manifest that in approaching a central point they would gyrate as the hands of a watch laid on its back. Between these columns of violent up-moving action there would be a point or space of more or less magnitude, where there would be a calm, from which the wind would blow towards the up-moving columns on each side, and therefore the air would come down over this calm region, and then so far from producing cloud over that region, the clouds pushed over it above from the adjacent up-moving columns would be dissolved by the heat of increased pressure as they descended, and thus would produce a clear space over the region of calm.

"In the meantime there being but little air between the up-moving columns and abundance on the outside to supply air for the upward motion (for these two columns are supposed to be closer together than the others beyond them), the columns would approximate and finally coalesce, and during this process an observer would see the clear space over his head, called the 'eye of the storm,' with that dismal, dark, lurid appearance, closing in upon him on all sides, so vividly described by various mariners.

"During this state of things there would be an increase of heat from the radiation of the abnormally heated air above, there being no clouds to intercept the radiation, and if any of the air, itself thus abnormally heated, should reach the observer below, the heat would be very oppressive. During this calm, also, the sea would be violently agitated, and the barometer would be a few hundredths of an inch higher than it would be in the centres of the ascending columns on each side.

"The same appearances may take place when the centre of a completely formed hurricane passes over an island. The wind may glance up round the borders of the island in such a manner as to form a ring of violent action all round the borders of the island, and the 'eye of the storm' may be formed over the calm in the middle of the island, in the manner just described. Nor is it unreasonable that such a phenomenon should appear in the open sea in a hurricane of great diameter, for the air coming in on all sides under the storm cloud, where the barometer is much depressed, will slope upwards and condense all its vapor that it

can condense, by the cold of expansion from diminished pressure, before it reaches the centre; and, as there will be in this case a calm of considerable magnitude in the centre of the storm below, it is manifest that there is no air going up from that region, and the small piling up of the air in the upper part of the atmosphere, caused by the inward and upward direction of the air in the parts of the storm around the central space, might make the barometer rise over the calm space four or five hundredths of an inch above that of the regions of the storm where the air was ascending with great rapidity; the air, in the central part of the storm, would thus gently descend, which would cause any thin cloud, which might be thrown over this space from the clouds around, to disappear very soon by the heat of increased pressure as the air over the central space descended, and thus would be formed the 'eye of the storm' in the open sea."

It is unnecessary to discuss in detail the many reasons why this theory is at present unacceptable. The most important point to note is the attempt to explain the presence of a descending current. It was an established fact that the eye of the storm was unusually free from clouds. Espy saw that this condition was best accounted for on the supposition of a downward movement of the air.

Descensional Movement. — Much of the later discussion has turned about the presence and the cause of this descending current. At present the fact of a descensional movement, though perhaps a slight one, appears to be sufficiently established. As the centre of the cyclone is a region of inflowing humid winds, which in their ascent immediately about the eye give torrential rain, the clearing away of the clouds in the eye itself can be accounted for only upon the supposition that the air is in some way heated, and that this heat dissolves the vapor. As it is a well-known fact that the compression of descending air increases its temperature, we have in a gentle descent or settling of the air an adequate, and apparently the only probable cause for such heating.

Other explanations. — We must note, however, another theory that has been advanced upon this subject. In a discussion* of the records at Manila during the centre passage at that place, J. M. Pernter proposes the following explanation of the remarkable decrease of the relative humidity.

* Oesterr. Zeit. 1883, 68.

"As the most violent winds are pressing spirally against the middle with enormous speed, at this place, then, the movement will be almost immediately checked by the arrival of the winds from all diametrically opposed directions. The kinetic energy which lay in the mechanical movement of the air, after the latter has disappeared will re-appear as heat; the sudden increase in temperature must necessarily result in the great dryness."

This view, however, has been sufficiently answered by Köppen,* as follows:—

"The indications of the registering apparatus of the observatory at Manila during the great hurricane whose centre passed over that city at the noon of Oct. 20, 1882, seem to make the conclusion of a descending current, at least in the centre of *this* hurricane, unavoidable, for at the beginning of the calm, the temperature rose suddenly seven degrees [C] and the relative humidity sank from one hundred to forty-three per cent†, while after the passage both elements returned immediately to their former state. In the 'Oesterr. Zeit.' 1883, pages 64–68, where these curious facts are illustrated by a diagram, the attempt is made to be sure to explain them through the transformation into heat of the converging movement of the masses of air, which stop suddenly in the centre of the hurricane. However, such a transformation could take place only through increase of pressure, while the inflowing air so far as it flowed horizontally was actually exposed to a powerful diminution of pressure. Although we have as yet no such precise and complete data for any other case, the breaking open of the lower cloud stratum in the center has at least been confirmed so many times that this appearance of descending currents here seems to be a general phenomenon, which, however, does not extend, or not always, to the height of the cirrostratus layer."

One further objection to the presence of a downward current has been raised by W. L. Dallas in his 'Storms in the Arabian Sea.'‡

Mr. Dallas quotes a number of the cases where butterflies and small birds have been found in the eye of the storm, and concludes:

"In these instances the cyclone has been met with at a very considerable distance from land and it is inconceivable that such light objects as butterflies, insects and small birds could remain

* Met. Zeit. I., 1884, 275.

† This error was copied from Pernter. The correct reading was fifty-three per cent.

‡ Cyclone Memoirs, Pt. IV., 422.

for any long period within a column of air which had any large ascensional or descensional movement. That there should be no gyratory movements at the centre of a cyclone agrees with theoretical deductions, but it has been popularly supposed that both in the case of waterspouts, and of cyclones, the central calm area is formed of a column of air in rapid ascent. On the other hand, certain recent writers have suggested, from the humidity changes observed during the passage of the calm centre, that the column is really the seat of a descensional current. The presence of insects and butterflies seems to negative both these suppositions, and apparently leads to the conclusion that within the calm center, at the level of the sea, there is practically no motion either upward or downward."

It is true that the presence of butterflies and small birds precludes the idea of any large ascensional or descensional movement; but this should not be generalized to the point of saying that there is practically no motion either upward or downward. When the proportions of the calm centre are considered, — those of a flat disc with its base two or three times its height, — it will be seen equally that there can be no downrush of air as through a tube-shaped cylinder, but rather a gradual settling of the air over a wide area. Such a settling would give all the meteorological phenomena observed, such as the clearing away of clouds and increase of temperature, long before it reached such a point as to be fatal to the butterflies.

Cause of descent. If then we are to admit the presence of a slow downward movement of the air, — and the prevalent clearness of the air seems inexplicable on any other hypothesis, — we must next inquire into its cause.

Espy, it will be remembered, sought to explain it by the radial indraft of winds, ascending as they flowed towards the centre, and so piling up in the upper regions of the atmosphere. This view, however, since the complete demonstration of a spiral inflow, can be no longer held.

As far as I am aware, there has been but one other explanation offered to account for the downward movement: that given by Ferrel. I shall quote from his last work.*

"If the conditions are such in the upper part of the atmosphere, that the ascending current becomes colder instead of

* Popular Treatise on the Winds, N. Y., 1889, 313.

warmer than the surrounding part of the atmosphere, of course it ceases to ascend, and is deflected off horizontally in all directions before reaching that level. As the gyratory motion depends upon the vertical circulation, this, at least at first, extends up to this level only, but the strata above may be acted upon more or less by friction. The air charged with moisture, in its vertical circulation, in toward the centre below, up in the interior to a given altitude, and outward above in the middle strata, necessarily moves in a path somewhat elliptical, so that it is being deflected outward, above, and still ascends until at a considerable distance from the centre; and so there is little condensation of vapor in the central part, and the cloud stratum is thin, sometimes entirely wanting. And this state is still further promoted by the gyratory motion, which is confined mostly to the lower and middle strata, bringing the air down from above, it may be, down pretty low, into the interior central part, where it is carried out horizontally on all sides, and the descending air in the interior above is of course clear air.

"The tendency of the air in the interior of a cyclone to settle down is no doubt caused often by the falling of a great amount of comparatively cold rain from the upper strata, which, both from its weight, which is partially sustained by the air in falling, and also from the cooling effect, increases the downward pressure in the centre. And this would especially be the case in tropical cyclones, where the air ascends more vertically and symmetrically on all sides, and the rain is not mostly carried away in front of the centre before it falls. Hence the central partially or wholly clear space is mostly observed in these cyclones."

None of the three causes given, however, appear entirely satisfactory. In seeking an explanation for the clearness, in the elliptical movement of the air, Ferrel does not appear to consider the great breadth of the calm centre. Such a cause seems entirely inadequate to explain the disappearance of the clouds over a space ten to twenty miles in diameter.

For the second point, it is not quite plain how the gyratory motion brings down air from above, especially as the air of the gyratory circulation is itself ascending about the centre. And the possibility of the clearness being aided by the falling rain is negatived again by the great diameter of the calm over which no rain is falling.

What then is the cause of the clearness of the eye? The following is proposed as a rational hypothesis, which appears to be borne out by the facts.

The wind of the cyclone is prevented from reaching the centre by two causes. First, as the wind velocity increases, the deflective force of the earth's rotation increases, until around the centre the hurricane winds blow in a circle. Secondly, the air is carried upward and outward by the convectional circulation before reaching the centre.

Thus we have a revolving circumference of violent winds, with a calm in the centre. But the winds by their friction must tend to drag the calm air adjacent to them into the cyclonic whirl. Possibly, also, there is a tendency of the circumference of winds to expand by centrifugal force. In either case there would be a deficiency of air at the outer edge of the calm, which would have to be supplied by a gradual settling of air over the whole area. Such a settling would be sufficient to dissolve the cloud stratum and to show blue sky.

NEED OF MORE OBSERVATIONS.

But, perhaps, the most apparent lesson of this whole discussion is the need of more observations of meteorological importance concerning the eye of the storm. We cannot reason to any advantage until we have a sufficient ground-work of facts; and with the present confusion of data upon this subject any great advance appears impossible. What is especially desired, and what will be gladly received by the writer, are first-hand observations of *sky conditions, cloud appearance and movement, barometric, thermometric, and humidity changes*, during the calm passage. It is hoped that other meteorological publications will join in calling for these significant facts in place of the phenomena of wind and water which usually receive the most attention; so that the centre passages of the next few years will lead to a better understanding of the eye of the storm.

HARVARD COLLEGE, CAMBRIDGE.

RECENT EFFORTS TOWARD THE IMPROVEMENT OF DAILY WEATHER FORECASTS.

H. HELM CLAYTON, LOCAL FORECAST OFFICIAL.

THE object of this article is not an exhaustive treatment of the subject, but merely a brief description of such work as has come under the notice of the writer, and a statement of his own efforts in this direction.

There are two methods which may be used in making weather forecasts. One has been called the "deductive method" and may be described as deciding from well-known laws of physics what will be the future action of atmospheric disturbance already in action and where future disturbances will appear. The other will be called the "inductive method" and may be described as deciding, from rules or laws derived from experience, without regard or without knowledge of their cause, what will be the succeeding weather.

An intense amount of labor has been devoted to the effort to explain atmospheric disturbances in accordance with the laws of physics by such able men as Ferrel, Mohn, Guldberg, Hann, Köppen, Sprung, and others; and Prof. Abbe has recently written a book on "Dynamic Methods of Weather Prediction." Great advance in this direction has undoubtedly been made; but so far the art of weather forecasting has been almost entirely unaffected by it. Yet it seems almost certain that weather forecasting will not reach its highest development until the laws developed by induction have been explained and expanded so that deductive methods can be successfully used in forecasting. In other words, deductive method is the goal toward which we are moving. These methods are explained by Prof. Abbe in a book so easily accessible (Chief Signal Officer's Report, 1887, Part II.) that it would be unnecessary to review them here.

The rules established by induction on which weather forecasting chiefly rests are as yet comparatively few.

The basis of fully three fourths of all daily weather forecasts

is the law discovered by Benjamin Franklin, namely, that weather changes tend to move from west to east, supplemented by the fact that a given storm is likely to continue moving during a succeeding interval, as, for instance, twelve hours, as it did during the preceding interval of the same length.

The second most important law regarding the movements of storms was discovered by Ley, namely, that storms tend to incline slightly inward toward and to move around areas of low temperature, leaving these areas to the left of their track.

The next most important law, namely, that areas of high and low pressure mutually affect each other's movements was worked out by Loomis, though perhaps previously discovered. He showed that an area of high pressure to the north or east of a storm tends to retard the storm's movement and deflect it toward the north ; while on the other hand storms move most rapidly and most westerly when an area of high pressure is located to the south or southeast of the storm. He also found that a second storm in the rear of a preceding one tends to retard and deflect the latter.

Another important law, which, however, up to the present has been but little used in forecasting, is that storms tend to drift in the general direction of the higher clouds which outline the general direction of the atmospheric movement prevailing around the storm. This law was more or less worked out by Ley, Hildebrandssen, and others, but received its strongest demonstration from Forstèn who showed that in Europe storms from different directions coincided in their movements almost exactly with the mean direction of the cirrus clouds prevailing around them. This law connecting the movements of the higher clouds with storm movements has been greatly strengthened by the observations, at Blue Hill, from which it has been shown that the mean velocity of storms in the United States varies from month to month and from year to year almost exactly in proportion to similar variations in the mean velocity of the cirrus clouds. Möller and Köppen have taken a great step toward aiding in the practical application of this law, by showing that from the pressure and temperature observed near the earth's surface one can calculate approximately the pressure at any given altitude in the atmosphere and draw isobars for that altitude, as is done at sea level. Then if storms are largely controlled in their movements by the

general drift of the atmosphere around them it would be possible to determine approximately the direction and velocity of this atmospheric movement at any or at all levels, and thus map out the direction and velocity of storm movement. That the clouds at various levels do follow approximately the isobars calculated for those levels is clearly evident from the observations at Blue Hill. In the cirrus region the calculated isobars generally run from west to east with the gradient from the south, and the cirrus generally move from west to east; but when the cirrus have been found moving from the south the upper-air isobars have been found running from south to north with the gradient from the east, and when the cirrus have been found moving from the east the upper-air isobars have been found running from east to west with the gradient from the north.

Next in importance to the laws governing the movements of weather changes are those concerning the relation of each element to the distribution of atmospheric pressure.

It has been found that the wind blows spirally around regions of high and low pressure, moving outward from regions of high and inward toward regions of low pressure, and the velocity is proportional to the difference in pressure along the line joining the two, or, in other words, is proportional to the gradient. The temperature is found above normal on the east side of areas of low pressure, and below normal on the west side, and the reverse for areas of high pressure. The cloudiness and rainfall are found related to the shapes of the isobars on a weather map. This relation has been discussed by Abercromby, who distinguishes seven distinct shapes of isobars, and describes the weather associated with them. In general, it may be stated that most of the rainfall and cloudiness occurs in front of, and within, areas of low pressure.

The laws next in importance, in daily weather forecasting, are those concerning the effect of local causes, and of annual and diurnal periods in modifying the distribution of the weather in areas of high and low pressure. It is clearly worked out that mountains cause an irregular distribution of the rain in storms, the rain being in excess on the windward and deficient on the leeward sides of the mountains. Mountains also affect the temperature, and cause the winds of the Föhn type. Valleys cause large ranges in temperature and deflect the winds.

The hope of improving daily weather forecasts by the inductive method lies in the clearer determination of the above-mentioned laws, and the discovery of new laws, until rough approximations can be replaced by exact measurements or calculations.

The first in importance is to determine more accurately the laws governing the movements of storms and weather changes, for, until it is known where a storm is going to be located at the end of twenty-four hours, an exact knowledge of the relation of the temperature, winds, and rainfall to its centre, or to its shape, will be of little use. The most common method of endeavoring to obtain a more exact statement of a law is by means of averages. Thus the direction and velocity of storm movements have both been averaged; but the trouble with all such averages is, that variations from the average are so great and so frequent that a knowledge of the average is of limited use. However, averaging is one of the most available methods of attack, and by discriminative averaging and the use of the theory of probable error it may be possible to determine conditions where the variations are small.

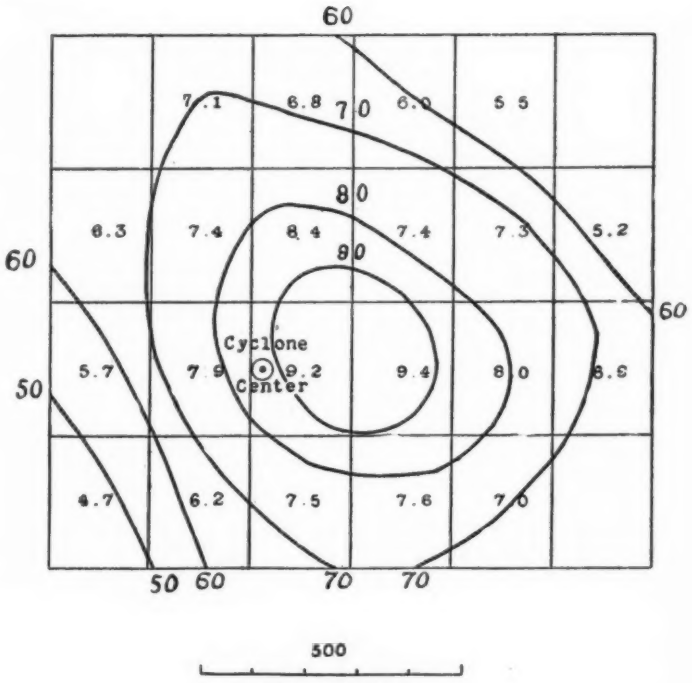
In the practical application of averages a law of averages discovered by Francis Galton may, with advantage, be used in weather forecasting. This law is that if any given occurrence deviates from the average in a series of occurrences of a phenomenon each derived from the preceding, the succeeding occurrences will tend to be one third nearer the average. Galton only applies this to heredity, but it is probably universal. For example, if a storm during a given twelve hours has moved with a velocity below the average, the probability is that it will move with a velocity one third nearer the average during the next twelve hours. It is very common in weather forecasting for the predicting officer to trace out the track of the storm and to locate the storm's position at the end of the next twenty-four hours on the supposition that it will move in the same direction and with the same velocity that it did during the last twelve or twenty-four hours. However, if there are no known reasons why the storm should differ, it is safer to assume that the direction and velocity of the storm will approach the average to the extent of about one third of its previous departure from the average.

Another method of research frequently tried is to find types

or classes into which weather conditions may be divided. Abercromby describes certain types of isobars which affect the weather of England. Teisserenc De Bort and Van Bebber have worked out typical isobars and storm tracks which affect the weather of Europe. In Sweden, Hildebrandsson has drawn up a large number of typical weather conditions which have been used in telegraphing weather forecasts. In America, Upton has tried to classify the storms of New England, and Russell the storms which accompany cold waves in the United States. The writer also tried the arrangements of storms into types containing all similar cases, but found, as others have found, that the number of possible combinations are infinite, and the number of actual combinations of different conditions are so immense that such types have a very limited use in forecasting. Even when a storm is occasionally found which appears almost exactly like a previous storm with which it is classed it generally fails to act like the previous storm, and overturns expectations based on it.

But if weather forecasting is to be improved the laws governing the movements of storms must somehow be more accurately determined; and, with this end in view, the chief of the Weather Bureau has directed the writer to investigate the connection between the movements of storms and the movements of the higher clouds. In order to do this he has found it necessary to classify storms, and is attempting to do it very thoroughly, so that not only the relation of storm movement to the cirrus may be investigated, but also every one of the previously mentioned laws.

The first step was to classify all areas of high and low pressure by date and position. For locating the position, five degree squares, into which charts are usually divided by the lines of latitude and longitude, and the centres of the high and low pressure areas, were selected. The squares on the maps of the United States were numbered, and whenever an area of high or low pressure was central over any square the date was entered under the number of that square. In doing this only the position of the centre at the time of the morning observations in the United States was used. The centres of the high-pressure areas were taken from the daily maps of the United States Weather Bureau, and the centres of the low-pressure



AVERAGE CLOUDINESS IN DIFFERENT PARTS OF A CYCLONE AT BLUE HILL OBSERVATORY, READVILLE, MASS.

areas were taken from the charts in the "United States Weather Review," which show the tracks of these areas. These latter were farther subdivided according to the direction from which they moved, using the eight points of the compass, and the number of the square and the date were entered under the heading of the point from which the storm moved. To this was added the velocity of the storm, — whether slow, medium, or rapid, whether increasing or decreasing in velocity, — and also the place of origin of the storm. In another column was given the shape of the isobars, — whether circular, elliptical, or elongated, — and also the direction of the longer axis, the lowest (or in high areas, the highest) isobar, and whether the pressure at the centre was increasing or diminishing. Another heading gives the shape of the isotherms, their density, — that is, the number within a given area, — the place where they were closest together, and the direction of the temperature gradient.

This classification when complete will enable a thorough study to be made of the statistics of storms and storm relations.

As an example of one of the applications of the classification, the accompanying chart is given showing the average cloudiness observed in different parts of a storm: —

The data for this chart were obtained by entering in the same column the observed cloudiness in every case when Blue Hill was located in a five-degree square east of a storm centre, and then in the same manner for every case when Blue Hill was located in a five-degree square south of a storm centre, and so on for each five-degree square around and at successive distances from the storm centre. The mean cloudiness for each square was placed in the centre of the square and isonephs drawn for each increase of ten per cent of cloudiness. These isonephs show that the centre of the cloud sheet and the maximum cloudiness are about two hundred miles in front of the cyclone centre, and over an area several hundred miles square the cloudiness averages more than ninety per cent. On every side of this area the average cloudiness diminishes pretty regularly, but most rapidly to the southwest of the cyclone centre, and beyond four hundred miles southwest of the cyclone centre the cloudiness is below the average of the year, which is near fifty per cent. Over the area inclosed by the line of ninety per cent it is found that the most frequent clouds observed are those whose

bases are below the top of Blue Hill, that is, only about one hundred meters above the level of the surrounding country. The distribution of the frequency of rainfall around the cyclone centre is very similar to that of the cloudiness. The number of cyclones (or areas of low pressure) used in forming these averages was five hundred and twenty-one.

BLUE HILL OBSERVATORY, READVILLE, MASS., MAY, 1892.

THE SEA-BREEZE AT COHASSET, MASS.

W. C. APPLETON.

THE New England Meteorological Society's Report on Sea-Breezes for the summer of 1887, has brought to my mind my own recollections on this subject. As they are the result of eighteen summers spent on the shore of Massachusetts Bay, they may be in some slight degree worth recording.

During the time referred to I have lived at Sandy Cove, in the town of Cohasset, in a house just above high-tide mark, facing the open sea. Minot's Ledge Light-house bears about east-northeast, two miles away. The shore tends northwest and southeast. A large part of my time has been spent sailing a small cat-boat in the neighboring waters, and I have thus of necessity observed the sea-breeze in almost all its variations. When the length of your trip and the time of your return often depend on this breeze, you soon learn to remember at what hours it is likely to begin and end.

I have carefully read the statement of Mr. T. W. Harris (N. E. Met. Soc. Investigations for 1889, p. 246), as to the action of the sea-breeze on the Cohasset shore. While I have seen it act as he describes, I feel very sure such action is exceptional, inasmuch as the various wind changes usually take place at a later hour than he indicates.

I should describe a typical sea-breeze day, or as the fishermen call it, a "round-about" at Cohasset, as follows:

At sunrise there is a light, steady draft of air off the land from about due west. The sky is clear, except along the northwestern horizon, where the smoke from Boston hangs like an autumn haze over the harbor. The air has a fresh, cool feeling. By

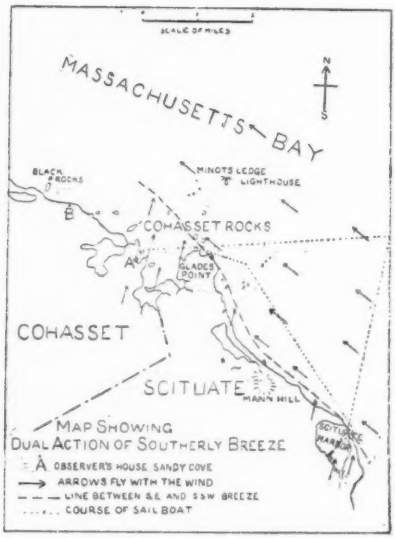
seven or eight o'clock the wind has veered to about northwest, drawing along the shore in a fairly brisk fashion, while two or three miles out to sea it begins to fall calm. By nine or half past the sea is like glass, except for a strip within half a mile of the shore, where there is a pretty steady draft from between northwest and north, about parallel with the trend of the shore. In the offing there are possibly a few "cat's-paws" from the north. About ten or half-past the cat's-paws veer in an irregular, hesitating way to the northeast. Soon some of them spread, and advance in patches landward, till very likely we get a refreshing, though very light, northeast breeze, even at the shore line. This generally dies away in four or five minutes. Sometimes it is repeated several times. Finally, at about eleven or half-past, we see out by the light-house a clear, crisp ripple on the water. It advances inland at a moderate speed, till at length we feel on shore a steady breeze from the east. The sea-breeze has at last set in. Gradually it veers and increases, till in an hour from its definite beginning it is blowing briskly from the southeast.

If the morning has opened almost calm, as I have described, the sea-breeze shows little sign of falling till nearly five P. M., or even past five; but before six it is pretty certain to weaken, at first slowly, then more and more rapidly, till by six the sea is again nearly calm. Then gradually there comes a light, steady draft from the south or south-southwest, soon veering to southwest, and increasing to a fairly steady breeze of moderate force by seven or eight o'clock. By nine or ten it may have veered to west-southwest, but almost never any nearer west than that, even at midnight.

This I should call the "round-about" or sea-breeze day in its perfection, and as it actually occurs more often than in other forms, still, its variations are innumerable. If there is a pretty brisk southwest breeze in the morning, the sea-breeze may come, if at all, with fewer preliminary breathings. Sometimes, but not often, it begins as early as nine o'clock. Sometimes it ceases suddenly in the early afternoon, even as early as one o'clock. In such cases it is driven off almost always by a southwest breeze, which comes in a strong, hot puff, and continues blowing with considerable force all the afternoon. This is doubtless the prevailing summer wind. May it not, however, be enabled to overpower our Cohasset sea-breeze thus early by aid

of the Buzzard's Bay sea-breeze, which might reach us in the first part of the afternoon?

As to the approach of the sea-breeze, I have observed it three or four times from a point on the Jerusalem road [marked B on the accompaning map*], on the crest of the shore rocks, about 30 feet above the sea. This place is about a mile and a half northwesterly from Sandy Cove. Here I have felt a steady, cool



draft from the northeast, though the sea directly below and for a mile or so from shore was like glass, while further in the offing it was rippled by the first coming of the sea-breeze. This would certainly seem to indicate an upward tendency in the breeze as it moves landward. The general conditions accompanying this occurence make me believe it is usual on sea-breeze days.

There is another action of the wind at Cohasset and Scituate (the next town to the south), which occurs normally perhaps three or four times each summer. I imagine it is the result of the sea-breeze tendency acting on a somewhat peculiar shore line, when

* While the place referred to is indicated upon it, the map as a whole illustrates a wind action entirely different from that now being described.

cyclonic conditions favor a strong southwest wind. I have never seen it reported elsewhere.

This action takes place oftenest, I think, on a damp, muggy, hot day. The wind is always strong, — frequently strong enough to make small sail-boats reef. At Sandy Cove its direction is distinctly south or south-southwest, — seldom west of south-southwest, never east of south. In the forenoon, often as early as nine o'clock, you notice the sea beyond the Glades Point is dotted with white-caps such as an off-shore breeze does not produce. If you sail out there, you find the breeze everywhere to seaward of the point strong southeast, cool and fresh. The dividing line between the two breezes is sharp and distinct, in about the position indicated on the map. It often remains nearly fixed for hours, till finally (generally early in the afternoon) the land-wind overcomes the sea-wind, and makes its way rapidly off shore, till all signs of the latter disappear.

The enduring character of this dual breeze was illustrated on a short sailing trip which I recollect very clearly. We left moorings in Sandy Cove at 9 A. M., and stood out to the Glades Point with a hot south-southwest breeze. Opposite the point our sail suddenly hung slack, and before we had shot forward more than a rod or two filled again as we hauled in the sheet, but this time with a fresh, cool southeast breeze. We stood out to sea close-hauled for some miles, where the strong breeze raised a heavy "chop" that drenched us with spray. Tacking in the offing we stood in for Scituate Harbor. As we entered its narrow mouth, the wind struck us from the south-southwest again; and so sudden was the transition that we were still shivering cold and wet, though the air was about 85° in the shade. After stopping an hour we started for home. At the harbor's mouth we struck the cool southeast breeze, before which we quickly reached the Glades Point, about five miles from Scituate Harbor. Here we found the hot south-southwest breeze as we had left it some four hours before. On landing at Sandy Cove about one P. M., we learned that no hint of a cool, southeast breeze had been felt there. The whole morning had been hot and oppressive.

I remember on another day, with similar winds, sailing in towards Mann Hill, Scituate Beach, with a cool southeast breeze. [See map.] When about 500 feet off the beach we struck the

south-southwest breeze, intensely hot. Tacking, we quickly entered the southeast breeze again. We repeated the experiment several times with the same result, proving the dividing line between the two breezes to be a fairly permanent one.

[NOTE: The record of Mr. T. W. Harris to which the author refers is given as follows in the Investigations of the New England Meteorological Society for 1889. "The succession of winds ordinarily taking place on the south shore of Massachusetts Bay in the fair summer weather is as follows: Before sunrise there is a steady light, west northwest breeze; about half an hour after sunrise this dies away, and fifteen or twenty minutes later a light east or northeast breeze springs up, apparently beginning from one to two miles from shore; it requires some time to reach the land. During the morning, the breeze gradually shifts around to the east and southeast, coming to the southeast as a steady moderate breeze about noon. About two or three o'clock in the afternoon, the wind shifts, after several uncertain attempts, quite suddenly to the southwest, and gradually increases in force, with many flaws, till about sunset. Then the flaws become infrequent, and after slowly shifting to the west, it settles down about nine o'clock to the west-northwest again, where it holds all night, decreasing in force till morning." Ed.]

TEMPERATURE SEQUENCES.

PROF. H. A. HAZEN.

AN interesting article on "Method in our Winter Temperatures" appeared in the April number of this JOURNAL, and the subject is of sufficient importance to merit still further discussion. There is a familiar principle in meteorology that the temperature, pressure, wind, or any other meteorologic element has a tendency to recover itself; for example, if the temperature has been very low for a month or two we may anticipate the contrary condition shortly. Whether this recovery follows any general law, or whether there is an average member of months which may be regarded as following this rule, and how many, has never been accurately determined, though there seems to be no reason why such an average might not be found if it existed.

In the autum of 1882 the present writer presented a paper to the Philosophical Society of Washington, D. C., which was published in the Transactions for 1883, on the probability that any summer which was above or below the mean would be followed by a winter of the same or opposite character.

The observations at Providence, R. I., for fifty years were tabulated according to the mean temperature for each summer and

winter, and it was found that, in forty-eight per cent of the cases, any summer above or below the mean was followed by a winter of an opposite character, in forty-two per cent the summers or winters showed very little variation, and in only ten per cent of the cases were the following winters of the same character as the preceding summer. The same results were also obtained at Ft. Snelling, Minn., from the observations for thirty-four years.

In the paper before us, the November or autumn temperatures have been compared with the following winter, and it would appear that the result is just contrary to that found above, at least for Philadelphia, Penn. It also appears that when a winter is cold or hot the three preceding and four following months show the same characteristic; that is to say, the tendency appears to be for nine consecutive months to show the same peculiarity. This is certainly a most remarkable showing, and seems to indicate a flaw in the method of treatment, for we know perfectly well that there are no sequences in our temperature conditions for so long a period. One difficulty in this discussion is the shortness of the period included. Observations for twenty years will give us a pretty good idea of the mean temperature of a place and the extremes that are likely to occur, but it would be altogether too short a time to settle a question of this kind. I think, also, that there is a variation in the observations published from this station. I have taken the record as given by Prof. Lorin Blodgett in his "Climatology of Pennsylvania," published in 1889, and have found the following results for the twenty years given by Mr. Gawthrop, from 1825–1844: —

MEAN TEMPERATURE, PHILADELPHIA.

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.
8 warmest winters,	64.7	53.7	42.3	35.0	33.9	36.8	43.4	52.0	63.8	70.9
7 coolest "	65.7	53.6	43.7	33.0	29.3	28.1	40.2	52.5	62.8	70.5
5 average "	64.5	54.4	41.6	33.8	30.9	32.3	39.5	52.5	61.4	70.7

It will be seen that this table gives just the opposite result to that found by our author. The November temperature, which has been assumed as the key to the temperature of the succeeding winter, is 1.4° *higher* just before the cold winter than that before the warm winter. The autumn temperature, in like manner, is 54.3° before the cold winters and 53.6° before those that are above the mean.

We have at our command observations for sixty-four years at the same place, and it is of interest to determine what these indicate in their entirety.

We have also observations for sixty-two years at Ft. Snelling Minn., and for the same number of years at Chicago, Ill., if we count interpolated values. The following table exhibits the results at these three stations: —

WINTER TEMPERATURE COMPARED WITH PRECEDING AUTUMN.

	Years.	Opposite, per cent.	Same.	Average.
Philadelphia,	64	43	36	21
Ft. Snelling,	62	55	41	4
Chicago,	62	25	58	17

It will be noted that the conditions at Chicago are just the reverse of those at the other stations. It is plain from this table that it would be useless to attempt the prediction of the probable temperature of a coming winter from that of the autumn.

I have also counted up the number of times that the three winter months showed the same phase in temperature, that is, above or below the mean, and find that in the sixty-four years at Philadelphia there were only twenty-three winters, or thirty-six per cent of the cases, and at Snelling there were twenty-nine cases, or forty-seven per cent. This shows that the number of cases giving uniformly high or low temperatures for even three months is very small. It would be of interest to determine similar figures for other stations, though it is evident they would be of no use in predictions.

WASHINGTON, D. C., May 16, 1892.

CURRENT NOTES.

NEW ENGLAND ASSOCIATION FOR APPLIED METEOROLOGY.

A meeting of the directors of the Agricultural Experiment Stations and of the secretaries of the State Boards of Agriculture for New England was held in the rooms of the Massachusetts Board of Agriculture on Thursday, May 5, 1892. The following gentlemen were present and took active part in the discussions: Prof. G. H. Whitcher, Durham, N. H., director of the New Hampshire Experiment Station; Prof. F. H. Bigelow, Weather Bureau, Washington, D. C., representing the Chief of the Bureau; Dr. M. C. Fernald, Orono, Me., President of the Maine State College; B. Walker McKeen, Augusta, Me., secretary of the Maine Board of Agriculture; Prof. W. W. Cooke, Burlington Vt., director of the Agricultural Experiment Station and secretary of the State Board of Agriculture; N. J. Batchelder, Concord, N. H., secretary of the Board of Agriculture; Prof. W. H. Brewer, Yale Scientific School, New Haven, Ct., representing the Agricultural Experiment Station; Lieut. L. W. Cornish, Amherst, Mass., of the Massachusetts Agricultural College; Prof. W. M. Davis, Cambridge, Mass; Hon. W. R. Sessions, Boston, secretary of the Massachusetts Board of Agriculture; J. Warren Smith, Boston, director of the New England Weather Service; A. Lawrence Rotch, of Blue Hill Observatory; H. H. Clayton, of Blue Hill Observatory; and others.

The meeting was called to order by Prof. G. H. Whitcher, and on motion he was elected chairman of the meeting, with W. R. Sessions as secretary. After introductory remarks by the chairman, who was instrumental in calling the meeting, an address was presented by Prof. Bigelow on the effect of the sun and weather on vegetation. He gave an interesting explanation of the present electrical theory of the sun and its connection with the growth of vegetation, as shown by experiments in electroculture. Following that a paper prepared by Prof. C. D. Warner, on the value of self-recording instruments in meteorological work, was read by Lieut. Cornish. Prof. W. M. Davis then told of the lines of work to be taken up by the Experiment Stations to best advantage, showing how this should be done and then the best manner for giving the results of the investigations to the public. He urged the importance of more recording stations and more carefully kept stations with accurate instruments, and showed how the matter could be taken in hand with good results. He pointed out the necessity of extending the daily weather forecasts and frost warnings into the agricultural sections, and the need of educating the farmers to the value of them. He said that it was not fully proven just how far in advance the forecasts could be made with satisfactory

accuracy, and that one of the works of the stations and boards of agriculture should be to have a careful record made of the verifications of the forecasts for twenty-four hours and for thirty-six hours.

Prof. Brewer gave a short but practical talk on the value of forecasts and warnings and of the importance of systematic work, but said that the Connecticut Station had done nothing as yet regarding the investigation of smudges for protection against frosts, although they intended to take it up during the present summer. Mr. Sessions gave a practical account of the work carried on by his board for two years, in connection with the New England Meteorological Society, in the matter of printing a meteorological report in his monthly crop report, and thought there was an increased interest in this connection, and said that he was ready to take very active steps toward the matter under discussion. Prof. Cooke, of Vermont, could not see much advantage to be derived by the farmers from the issue of the bulletins, forecasts, warnings, or anything else. Owing to the peculiar geographical surface of his State, it must be a peculiar forecast that shall indicate accurately the weather for any two sections, and a few failures would make the information worse than nothing.

Mr. J. Warren Smith explained the province of the State weather services, and gave in brief the history of the New England Meteorological Society, which has been so long doing the State weather-service work for the New England States. He told of the transfer of this work to the National Weather Bureau, and the organization of a New England weather service, and then of the principal lines of work that the service was taking up for the benefit of agriculture in New England. He presented plans for co-operation among the experiment stations for the establishment of more voluntary observer stations, and for publishing their reports, for a wider dissemination of the daily weather forecasts and frost warnings, and for the larger issue of the weekly crop bulletins. He said that the great trouble was that people were ignorant of the advantages to be derived from the information which the Weather Bureau can give and also of the means of obtaining it, but that his experience while attending agricultural meetings during the past winter had shown him that they were anxious to obtain the information and were quick to take advantage of it.

Dr. Fernald then opened the question for general discussion: "How can the weather forecasts be placed in reach of the farmers?" He explained the methods now in use, their advantages and disadvantages, and then told of a system which originated at one of the local granges in Maine, for signalling the forecasts over a large territory quickly and easily. He was followed by an explanation of the plan by Mr. McKeen, and by Mr. Kendal, who originated the idea, and then a general discussion ensued on the points brought out by the papers.

It was voted to form a permanent organization, to be known as the New England Association for Applied Meteorology, its object being co-operation in the interest of practical meteorology, namely observation, distribution of the knowlege thus gained, and practical research. The membership is to be limited, and is to be confined to officials of the various boards and organiza-

tions actively interested. The following are entitled to become members: Director and one other member from the agricultural experiment stations, president and one other member from each agricultural college, president and secretary of each State Board of Agriculture, one member from each State grange, one member from each State Board of Health, three members from the New England Meteorological Society, to be appointed by the council for the Society, the chief of the Weather Bureau, the local forecast officials in New England, and the director of the New England Weather Service.

The following officers and committes were elected: President, Prof. G. H. Whitcher; Secretary and Treasurer, J. Warren Smith; Board of Managers, Prof. W. W. Cooke from Vermont, Mr. N. J. Batchelder from New Hampshire, Dr. M. C. Fernald from Maine, Prof. W. M. Davis from Massachusetts, Prof. W. H. Brewer from Connecticut, and Prof. Charles O. Flagg from Rhode Island. A committee was appointed to consider the association of this organization with the New England Meteorological Society, or the co-ordination of the work of the two organizations, and another to draw up a concise statement of the practical work being done at all the official institutions connected with this organization. The time and place for meeting next year is to be appointed by the Board of Managers. J. W. S.

WEATHER BUREAU.

A new line of policy has lately been adopted by this Bureau, or, rather, an expansion of the policy adopted when the system of Local Forecast Officials was established. The Local Forecast Officials are summoned to Washington City, in order, and given a two months' course of training in general forecasting. Two are summoned each month, and as there are twenty of them at present it will take about a year to go through the list. At the same time several officers in the Bureau at Washington are going through the same course of training. L. M. Dey, of Philadelphia, and J. W. Smith, of Boston, came on the 1st of May, and on the 1st of June W. H. Hammon, of St. Louis, and E. A. Evans, of Detroit, are expected.

Prof. Thomas Russell, of the Weather Bureau, is studying the lower Ohio basin, including the Tennessee, Cumberland and Wabash rivers, to be gone until July 1. He will put in some river-gauges and make a study of the quantity of discharge of the rivers named.

A study of thunderstorms similar to that which has heretofore been carried on in New England has been undertaken in the territory extending from Missouri eastward to Pennsylvania and New England. Certain observers of the Weather Bureau are authorized to receive telegrams from observers to the westward announcing the approach of thunderstorms, and at their discretion to predict the approach of these storms. A rather more complete test of thunderstorm prediction is to be made in lower Michigan by means of the telephone.

A special study is being made of the meteorology and currents of the

Great Lakes by the Marine Agent, Dr. H. J. Penrod, stationed at Cleveland. As a preliminary study, a wreck chart has been made, and issued to those interested in marine matters on the Great Lakes. It shows the point where each total wreck due to meteorological agencies has occurred. Recently a large number of current-bottles have been issued to masters of vessels and others on the Great Lakes, with proper arrangement for the registry of time and place of casting overboard, and time and place of recovery. It is hoped that they will throw some light on the hitherto practically unstudied problem of the currents of the Great Lakes. Systematic studies will be made of fogs and other meteorological features of the Lakes.

A bulletin of the climate of Death Valley, Cal., containing fifty octavo pages, will be issued by the Weather Bureau in a few days. It discusses the observations made in the valley for the five months, May to September, 1891. This is Bulletin No. 1, of a series which it is hoped will be a long and valuable one.

To-day appeared an advance copy of the Report of the Secretary of Agriculture for 1891, in which is included a report on the work of the Weather Bureau for the last six months of that year. This report covers nearly a hundred pages, and includes several matters of interest to meteorologists. Among the topics treated are, the distribution of forecasts and frost and cold-wave warnings; the weather map; flood predictions; State Weather Service Division; Pacific Coast Division; the study of meteorology in the United States, including a list of the colleges where meteorology is taught, the names of the professors teaching it, and the extent of the courses; a sketch of the meteorogical records of the United States, with especial reference to those filed in the Weather Bureau; meteorology and terrestrial magnestism; researches in soil-physics; and a report of the weather conditions of the crop of 1891, the last being prepared by Major H. H. C. Dunwoody.

A. L. C.

WASHINGTON, D. C., June 1, 1892.

Photography and Meteorology. — Mr. A. L. Colton, of the United States Weather Bureau, at Washington, D. C., has recently published an article on Photography and Meteorology in Anthony's *Photographic Bulletin*, from which the following extracts are taken: —

"Some attention has been given, especially at the Kew Observatory, England, to the photography of clouds for the purpose of determining their height, direction of motion, and velocity, and so studying the upper-air currents. I have seen occasional references to the subject in American literature, but, so far as I am aware, no practical work of this kind has been done here. Some very interesting results might be obtained, and the field is a good one for amateurs who care to make the somewhat elaborate preparation needed. Two cameras are required at a definite distance from each other. If the measurements are to be accurate the distance must not be too short, and the exposure must be made at the same instant, the instruments having been pointed so as to cover the same region of the sky. The height and position of a cloud in the field of view can be found by determining its location on each plate, finding the altitude and azimuth of the axis of each

lens, and applying suitable trigonometrical formulas. The work is greatly simplified by placing the cameras at the same level and directing the axes of the lenses vertically, the angle of view included by the lenses and the distance between them being so chosen that the fields largely overlap. Similar lenses should be used, and the plates should be of the same size. From successive observations of the same cloud, taken at different times, the direction and rate of motion may be found.

"Attempts have been made to measure the height, velocity, and direction of motion of clouds by eye observations with theodolites or similar instruments, but the photographic method has decided advantages. In the case of eye observations by two parties at a distance from each other there are great difficulties in the way of agreeing upon the exact spot to be considered, and, while following it with instruments, in making the observations simultaneous; but with photographic plates corresponding objects may readily be compared. Even in using the photographic method some means of communication between the observers is essential. Telephones are preferable, but a code of flag signals may be arranged.

"Simply photographing the clouds themselves is much easier, and cloud photographs present many features of interest. They aid in studying the typical forms of clouds and their progressive changes, and in the association of cloud forms with prevailing weather. Not only may they add to our knowledge of general types of clouds, but if the work could be sufficiently extended they would increase our knowledge of the local forms peculiar to different regions and climates. There are also types peculiar to single localities, and a collection of photographs of these would be of the greatest interest. Among these are the 'table-cloth' on Table Mountain, the clouds hanging over different volcanoes, etc. As very actinic light is reflected from the blue background of sky, as well as from most clouds, this work is attended with some difficulties, especially in photographing cirrus clouds. Orthochromatic plates are, of course, useful. Advantage can also be taken of the fact that the light reflected from the blue sky is partly polarized. If, now, this light be extinguished, or dulled, by the analyzer of a polarizing apparatus, the image of the cloud will appear more distinctly in the photograph. A good instrument for this purpose can be found in a plate of black glass, or obsidian. This method was described by Dr. Riggenbach, of Basle, in a paper read before the Royal Meteorological Society in November, 1888.

"There are many unsolved questions concerning the electrical phenomena of the atmosphere, and perhaps some of these can be brought nearer to a solution by the careful study of photographs of lightning flashes. Information may be obtained as to the length and breadth of the flashes, their position relatively to the earth's surface, their duration, their different varieties, and perhaps also the reasons for their sinuous path in space. A considerable amount of work has already been done in photographing lightning, but the results only show the need of more. The Royal Meteorological Society has probably done the most systematic work in making its large collection of lightning photographs and in classifying into types the flashes represented. The classification includes six distinct types.

"In the case of so transient a phenomenon as lightning, the sensitive plate is especially useful in preserving for deliberate examination the fugitive image of the flash. However, there are probably defects in the image, due to optical peculiarities of the lens and to reflection of the brilliant light by the back of the plate, and these somewhat add to the difficulties of the research. The reflection referred to can be partially or wholly obviated by using films instead of glass plates. Of course the photographing of lightning can be done only at night. The camera must be focused for distant objects, and it will be found useful in a variety of ways to have the bed of the camera marked for this purpose. By directing the camera toward the region of the sky in which the flashes are observed, leaving the lens uncapped, and capping it immediately after a flash has appeared within the field of view, a photograph can be obtained. On very sensitive plates there may be a reversal of the image, especially if a very rapid lens be used. This 'dark lightning' is likely to be invisible, as the background also is dark.

"By determining in some manner the interval of time between the flash and the report, the distance of the flash can be found; from this distance, the focal length of the lens, and the length of the image on the plate, the length of the flash might be approximately determined.

"It has been thought that the lightning discharge is oscillatory, and some experiments have been made which tend to confirm this view, by simply moving the camera with the hand at the time of the flash. The path of the lightning thus photographed has an oscillatory appearance. This is an interesting experiment and one not difficult to perform.

"Hoar frost presents a multitude of forms which are not only of interest to the meteorologist, but are exceedingly beautiful in themselves, and well worth the photographer's attention. Snow crystals also are both beautiful and interesting, and our knowledge of the processes of crystallization might be advanced by a careful study of these forms in connection with the circumstances of temperature and humidity accompanying their origin. These crystals are so evanescent that it would be very desirable for purposes of study to preserve their forms by means of photography. Of course, they must be kept at a low temperature until after the photograph is taken. As they are so small, some magnification would be useful. Hailstones also, their form, cross-section, etc., are excellent subjects to be included in this research.

"There are also various optical phenomena of the atmosphere, which have rarely been photographed, owing partly, perhaps, to the infrequency of their occurrence. Of this class are the mirage, the rainbow, and the solar halo. No favorable opportunity of photographing them should be allowed to pass unimproved."

Thunderstorm Investigation. — The following extract from a circular recently issued by the Chief of the Weather Bureau is self-explanatory: —

"The Weather Bureau desires to give special attention to the observation and investigation of thunderstorms and attending phenomena during the summer of 1892, and with this end in view the co-operation of meteorologi-

cal observers and others interested is earnestly solicited. The object of this work is to gather material to be utilized in the study of these storms and the attending atmospheric conditions with a view to predicting the occurrence of this class of storms for special localities in time to make the forecast of value to agricultural interests. The great advantage of receiving information as to the actual prevalence of violent thunderstorms in certain quarters of your State, with reliable predictions as to when such a storm will likely reach your own community, should be apparent to all, and as there is no class of citizens which would not be benefited by a system that would make such work possible, there should be no difficulty in securing the voluntary assistance of observers in such numbers as to supply ample material for this work. Upon such voluntary co-operation on the part of observers the success of the plan will largely depend. The field chosen for the proposed system of observations for the approaching season will embrace the region from the upper Mississippi eastward to the Atlantic coast, including the New England States, and if the results anticipated are realized, next year the territory will probably be extended to embrace the entire country."

The results which have been derived from the systematic study of thunderstorms in Europe, and from the study of the more meagre data which have been collected in this country, have shown the need of having many observers and a large field of observation in order to make such work successful. In undertaking this study with hundreds of observers over a large part of the northern United States, the Weather Bureau has started an investigation which should certainly lead to valuable results as far as the general features and the more exact prediction of our thunderstorms are concerned.

Effect of Glaciers on Winds. — An interesting note on the effect of glaciers on winds is found in a recent publication by Prof. H. F. Reid, entitled "Studies of Muir Glacier, Alaska."*

Prof. Reid spent last summer encamped close to the foot of the Muir glacier, on the coast of Alaska, and, in connection with numerous other studies, kept a continuous meteorological record during his stay there. He notes as follows: "The prevalent wind on the Alaskan coast is from the southwest, but the glacier, by cooling the air in contact with it, produces a cold wind, which slides down the slope. Thus a northeasterly wind blew continuously at our camp, except occasionally when a strong southerly gale overcame it. On the western tributary (of the glacier) the wind was from the west, and in Main Valley from the northwest; in fact, everywhere it flowed down the slope of the glacier."

In his "Klimatologie," page 203, Dr. Hann refers to winds caused in this way on the plateau of Quito, a description of which is found in Moriz Wagner's "Naturwissenschaftliche Reisen in Südamerika," page 355. The volcanoes of that region are covered with snow, and at certain times of the year, especially during August, September, February, and March, the winds which blow down from the snow-fields on to the level and barren plateaus

* National Geographic Magazine, Vol. IV., 1892, pages 19–84, plates 1–16.

are so violent that an ascent of the mountains is dangerous and even impossible. The greater the extent of the snow-fields and the greater the area of the barren plateau below, the more regular and the more frequent do these "Nevados" become. The writer quotes a case which occurred in September, 1858, when a caravan was detained a whole week at Quaranda, the violence of the "snow-wind" being such as to render any passage of the mountains very dangerous. These storms generally begin at the seasons when the regular thunderstorms of that region stop, and increase in violence when a number of clear sunny days succeed each other. The wind starts, as a rule, about 7 A. M., increases with the rise in temperature, attains its maximum strength about 2 P. M., and dies away after sunset.

The Effect of Low Atmospheric Pressure on the Vital Powers. — In a recent book entitled "Travels among the Great Andes of the Equator," Mr. Edward Whymper gives the results derived from his observations on the effect of diminished atmospheric pressure at great altitudes on the vital powers. By gradually ascending the higher mountains and encamping at different but constantly increasing altitudes, the author became accustomed to the decrease in pressure. From a large number of observations made during his stay in Ecuador, Mr. Whymper concludes that, after becoming accustomed to the rarity of the atmosphere, it is possible to sustain life at heights of 20,000 feet or more, when the body is at rest, but "when in motion it becomes difficult to enlarge the breathing capacity to the extent necessary to meet the further demand for air which was the result of muscular exertion."

Cloud Photography. — Drs. Neuhaus and Zettner give, in the *Photographic News*, the following formulæ for use in photographing clouds : —

To let through only the yellow and green rays

Cupric nitrate, 160 grams.
Chromic acid, pure, 14 grams.
Water, to make up, 250 c. cm.

To absorb the blue and violet rays

Cupric sulphate, 175 grams.
Potassic bichromate, 17 grams.
Sulphuric acid, 2 c. cm.
Water, 100 to 500 c. cm.

Clouds and Cyclonic Areas. — M. Vincent, meteorologist of the Royal Observatory at Brussels, has noted that a well-defined triple layer of clouds occurs with low barometric pressures. First, the cirrus or cirro-stratus, forming the uppermost layer ; second, the cirro-cumulus and alto-stratus, and third, the lowermost or rain clouds.

BIBLIOGRAPHICAL NOTE.

The Meteorology of India and the Surrounding Sea-Areas. — An interesting short summary of the meteorology of India and the surrounding sea-areas, by H. N. Dickson, F. R. S. E., F. R. Met. Soc., is found in the May number of the "Scottish Geographical Magazine." The principal work of the Indian meteorological service consists in forecasts, firstly, of the probable strength of the monsoon and distribution of rains in each year, and, secondly, of the occurrence of cyclones in the Bay of Bengal and the Arabian Sea. The forecasts with regard to the monsoon "are based on results derived by the method of abnormals from observations of the cold-weather snowfall on the Himalayas, the weather of adjacent areas, and the local peculiarities of weather in India itself, immediately before the advance of the currents. The first-named observations may be said to afford information as to the probable strength and penetrating power of the current itself, the second as to the chance of its being deflected from its normal course, as, for example, when a persistent depression over Burma may be fed by the Bengal current, and the third as to the local distribution of the rainfall, although the bearing of each class of data on the others is extremely important." The snowfall on the Himalayas is found to have a marked effect on the monsoon, a heavy snowfall being followed by a weak and late monsoon. The sudden bursting of the monsoon, which is noted in many accounts of India, has not yet been fully explained, but it seems possible that the cause may be connected with the production of the ascending current of warmed air from the great continental mass of Central Asia, a region which retains its anticyclonic conditions later in the year than India itself. To quote: "The Himalayas form a complete barrier to all surface winds; hence we have two ascending currents, — one, the smaller, fully developed over the peninsula, and another, much the greater, in process of formation, and gradually extending into the upper atmosphere. These are at first practically independent of each other until the second attains an elevation of ten thousand feet or more, and the barrier is surmounted. It is possible that on reaching that point the large vortex absorbs the smaller, just as two cyclones unite at ordinary levels; and we can conceive that the junction will cause a sudden demand on the lower portion of the latter, which is in this case supplied by the southwest monsoon."

The storms of the Indian seas, which have been so well studied of late, are divisible into two classes,—the cyclonic storms of the rains proper, which are seldom very violent, and the cyclones of the transition periods, before the middle of June and after the middle of September, which are the dangerous class, characterized by rotary gales of hurricane force, torrential rains, and the central calm, or eye of the storm.

PUBLICATIONS RECEIVED.

"Astronomy and Astro-Physics." Wm. W. Payne, director of the Goodsell Observatory, Northfield, Minn., and George E. Hale, director of the Kenwood Astro-Physical Observatory, Chicago, Ill., editors. Published ten times a year. The April and May numbers are at hand. The May issue contains, besides numerous articles of much interest, two contributions by Prof. W. H. Pickering, on The Mountain Station of the Harvard College Observatory, and on The Boyden Station of the Harvard College Observatory at Arequipa, Peru.

"Monthly Review of the Iowa Weather and Crop Service, in Co-operation with the United States Department of Agriculture Weather Bureau." Mr. J. R. Sage, director; George M. Chappel, M. D., Weather Bureau, assistant. March and April, 1892.

"Wisconsin Weather and Crop Journal," Milwaukee, Wis. Willis L. Moore, forecast official for Wisconsin, editor and publisher. Monthly. The May number contains, besides the usual meteorological data, articles on Forecasting Frost by Determination of the Dew Point, and on the Chinook Wind; also two reprints from the JOURNAL.

"Bulletin of the New England Weather Service, under the direction of the United States Department of Agriculture, Weather Bureau." J. Warren Smith, Weather Bureau, editor. Monthly, large octavo, ten pages. The March number is the first issued since the transfer of the work of the New England Meteorological Society to the Weather Bureau for the formation of the New England Weather Service. The Bulletin contains two pages of correspondence and notes, besides the usual data. The subscription price is one dollar a year.

"Monthly Review of the Colorado Weather Service, in Co-operation with the United States Department of Agriculture, Weather Bureau." Denver, W. S. Miller, director. The April number is at hand.

"Weather-Crop Bulletin of the Weather Service of the Kansas State Board of Agriculture, in Co-operation with the United States Weather Bureau." Topeka, Kan., T. B. Jennings, Weather Bureau, assistant director. Weekly, manuscript, with a chart of precipitation.

EDITORIAL NOTE.

IT gives us great pleasure to announce that Mr. Everett Hayden, Marine Meteorologist of the United States Hydrographic Office, Washington, D. C., has joined the staff of Contributing Editors of the JOURNAL. Mr. Hayden is already well known to our readers through his writings, and we feel sure that his connection with the JOURNAL will be a source of profit to its readers, as well as another step towards making the JOURNAL more influential and more representative in its line in the future.